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Life Cycle Design

A Manual for Small and Medium-Sized Enterprises

S. Behrendt
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Editors

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A Manual for Small and Medium-Sized Enterprises

With 46 Figures and 16 Tables

Springer

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Preface

Small and medium-sized enterprises can serve as promising cradles for challenging ideas and pioneering initiatives. That is exactly what is required in order to make progress towards sustainable levels and patterns of production and consumption. Of all the continents of the world, Europe is most likely to lead the way towards a more sustainable relation with the environment. Having been the cradle of the industrialized world as we know it today, Europe again will lead the way in the journey of discovery to sustainable industrial practice, that is, if suitable conditions exist, and engaged and motivated entrepeneurs take the challenge and the role of the pioneer. Essential to these conditions is a set of values regarding the availability and properties of resources, the functioning of products and the impact upon the environment, now and well into the future, in Europe as well as globally. Furthermore, imagination, information and encouragement will be essential.

This manual provides ideas, tools, examples and guidance for small and medium-sized enterprises (SMEs) that wish to develop products with the environment and the future in mind. It addresses product development and design with consideration for the whole life cycle of the product. This cycle is a process ranging from the identification and formulation of a need at the early stage of product development to the disposal of the product, after repeated usage, at the end of its life. A particular focus has been given to principles and criteria in the design of complex products.

Nowadays, waste disposal problems, reuse and recycling activities and future cyclic economies can no longer be discussed without reflecting upon the origin of the problems and the need for reuse and recycling. The level of consumption of resources, the character of production and the nature of the products that are continuously generated, force us to reconsider the basic assumptions, results and implications of our economic basis. This is especially the case if one considers the huge inequity between the industrialized and the low-income countries. Current environmental problems seem even more pressing if the predictions regarding the population of the future are taken into account. The overwhelming dominance will be in the developing countries. That is not only where the markets of the future are, but also where an even larger inequity gap could potentially split the world.

North and South should come and work together: by joining hands, ideas, knowledge and skills, the challenge of sustainable development can become a rewarding endeavour. SMEs in Europe could lead the way, as several have already shown. Governments could provide suitable conditions and the European Union could coordinate and stimulate debate, research and education as well as international cooperation. This manual is a contribution to that aim. It resulted from a European Commission (EC) research project (1 April 1995 - 31 March 1996), conducted by the IZT Institute for Futures Studies and Technology Assessment (Germany), which acted as project co-ordinator, IVAM Environmental Research (The Netherlands), IÖW Institute for Ecological Research in Economics (Austria) and INETI Instituto Nacional de Engenharia e Tecnologia Industrial (Portugal). Financial support was received from the European Commission, for which the management by the Socio-Economic Environmental Research Unit in the Environment and Climate Programme in Brussels is gratefully acknowledged. Hopefully, more EU initiatives directed to SMEs and the environment will follow and EU member states will broaden their policy to that end.

Of course, the authors hope that SMEs in countries outside Europe will also be able to take advantage of this manual. It brings together some of the European expertise regarding the sustainable product development of the future. It may also help to stimulate similar developments throughout the world. The result of this European cooperation should mark the beginning of global cooperation on sustainable product development, with European support.

UNEP-Working Group on
Sustainable Product Development

Dr. Hans van Weenen
Chairman

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1 Introduction

1.1 Need for a Manual

SMEs

The reason for writing this manual is that, throughout Europe, small and medium-sized enterprises (SMEs) are increasingly confronted with new environmental challenges such as product reuse and recyclability, product take-back (the return of goods to their producer at the end of their product life), and extended producer responsibility. Other, new issues that are gaining popularity in Europe are, e.g. the ecotax, the emphasis on product services and an orientation towards renewable resources. Some European SMEs have already achieved very positive results in resolving and avoiding environmental problems related to their products. New initiatives and joint pilot projects present attractive evidence for the economic advantages of the environmental improvement of products. Topics such as the environmental effects of products (refrigerators, electronic equipment, cars) and sustainable consumption are already emerging in societal and political discussions. At the same time, SMEs are faced with developments such as increasing globalization, information networking and local use of resources (van Weenen 1995).

European Union

Against this background it is important that the European Union can serve as a platform for information, exchange, research and development focused on the environmental opportunities for SMEs. The idea is to put them into a position in which information on good ideas and concepts is readily available. Educational programmes, role models and financial incentives can help SMEs enlarge their innovative capacity by using nature and environmental considerations as a source of inspiration. Thus SMEs can be better prepared or they can adopt proactive positions with regard to new, national and international regulations. SMEs can lead in environmental innovation rather than react to environmental requirements. This can be realized through well-informed choices regarding material use, manufacturing processes and the development of products and packaging.

1.2 Function of the Manual

Product development process

For small and medium-sized companies (SMEs) this manual serves as a source of information and ideas for environmental product development. It provides inspiration and structure for the environmental improvement of already existing products as well as for the development of totally new ones. The manual presents information and provides guidance at various levels of involvement and for different stages of the product development process. SMEs can use it to get new ideas, to find relevant background information or to follow guidelines for adjusting the product development process.

Most environmental problems are being dealt with by fighting against their negative effects, such as waste, emission and pollution. This is mostly done by technologies that are costly and directed at the wastes and emissions that have already been produced. From several demonstration projects throughout Europe, there is, however, increasing evidence that a reconsideration of processes and products will lead to new much more promising and even profitable approaches. At the European level the auditing process is a clear example of the new approach towards the environmental assessment of processes and products. From that, more and better information will result, which provides the basis for analysis and for the formulation of alternatives for improvement.

On the basis of a review of a product, it can be redesigned, so as to optimise its environmental impact all along the product's life cycle, from raw material extraction to manufacturing, consumption and disposal. However, an SME can also go further, back to the roots of the product, to the consumer needs, the product functions that have to be fulfilled, and to the basic properties of primary and secondary resources. An SME may also wish to improve its contacts with the customer, by involving customers and consumers more directly in the process of product redesign or new product development.

Life cycle design

Advantages are the potential cost saving, improved productivity due to a better development structure and by making use of practical experience of other companies. Examples can serve as an inspiration for new solutions and new directions. Life cycle design can lead to innovation and may show the way to new markets. SMEs which have gained experience with design for the environment may also become more flexible in reacting to new market developments and to the adoption of new technologies.

1.3 Design of the Manual

The environmental challenges for enterprises are dealt with in Chapter 2, which presents various solutions for reducing the burden on the environment, preventing future environmental problems and enhancing ecological innovation capacity and potential of SMEs. A new framework for SMEs is emerging, as they will have to function within the context of ecological product-design, ecoaudits, new laws and ordinances, ecolabelling, environmentally oriented consumer demand and new environmental standards and guidelines, which is covered in Chapter 3. The specific role that complex products play in the relationship between products and the environment is described in Chapter 4. Here many environmental criteria and product requirements must be fulfilled. It is necessary to systematically cover them.

The goal of the manual is to provide assistance to SMEs in incorporating environmental criteria into the product development process. This is presented in Chapter 5. The principles and criteria concerned are addressed in detail in Chapter 6.

To make clear choices is not always easy or even possible, the reason being that environmental criteria may conflict with one another. How to handle this problem is described in Chapter 7. From the various tools that exist, SMEs can choose the most suitable ones from those covered in Chapter 8. Of course, central to all of this are the costs involved, both the positive and negative aspects of which are highlighted in Chapter 9. The manual concludes with a number of practical cases for further illustration in Chapter 10.

The main objective of this manual is to serve as a source of information and ideas, to provide a working structure as well as incentives and strategies. It marks the beginning of a new and fascinating global direction towards sustainable development, in which SMEs, especially those in Europe, have a key role to play. This manual is meant to bridge the gap between economy and ecology, as well as between current and future practice.

1.4 Use of the Manual

The intention of this manual is neither to be exhaustive nor to present final answers. It is rather meant to emphasize the potential of making important changes as early as the conceptual stage, in which major economic as well as environmental progress can be made. The manual is a paper medium and therefore neither interactive nor flexible. The product development

process, however, is very dynamic, iterative and often quite complex. The manual can be used to search for ideas or information whenever required, depending on the stage of the development process users have reached.

The manual consists of three main parts:

Why? I. The introductory Chaps. 1-4, which contain arguments and information on WHY life cycle design should be practised.

How? II. The core of the manual is formed by Chaps. 5-9. Here a framework and tools are presented on HOW life cycle design can be realized. In Chapter 6, ecological principles are presented which provide the design team with generic strategies to improve the environmental performance of a product-design. Later on in the design process, more specific guidance is needed.

For this purpose, 13 ecological principles are elaborated in checklists which consist of a list of practical design criteria. An ABC rating scheme is added to each checklist to give an indication of the expected environmental relevance of each criterion for a specific design. These checklists offer practical guidance in verifying if all relevant criteria have been explored. In Fig. 1.1 an example checklist for the principle of "Saving Resources" is presented.

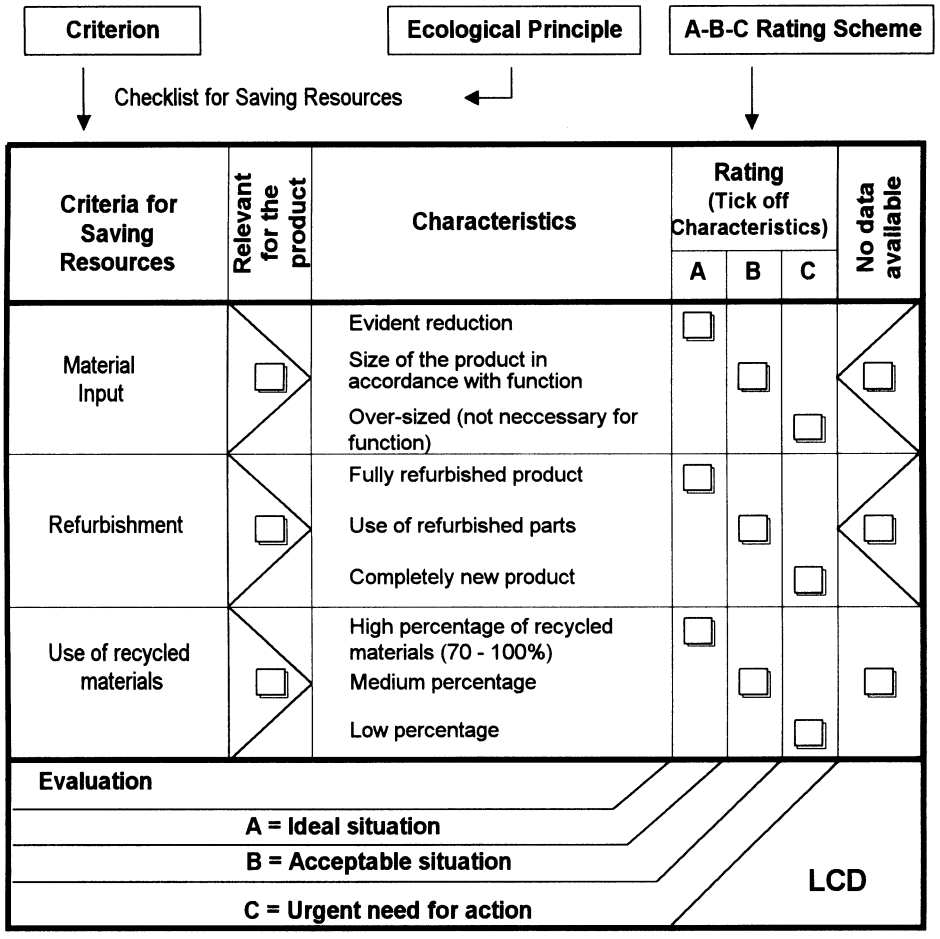


Fig. 1.1. An example of a criteria checklist

III. The future prospects of the manual are presented in Chaps. 10 and 11. These chapters address WHAT the manual may deliver and what other promises it holds. What?

2 Environmental Challenges for Enterprises

2.1 Dynamics and Limits to Growth

Globalization

Changes in consumer behaviour, increased product diversification, a decrease in the life span of products and, for example in the field of semiconductors, ever shorter innovation cycles, are signs of the growing dynamics of economic processes. In addition, there is a tendency towards the globalization of markets and production networks. This offers possibilities for new growth. At the same time, however, the physical limits to growth will be reached much faster. In the future, there will not only be a shortage of 'sources' of raw materials and energy but also of natural 'sinks' such as soil, water and air for the reception, absorption and transformation of emissions and waste.

Currently, it is mainly the small and medium-sized enterprises that are being exposed to a multitude of challenges. In the future, the increasingly dynamic economic system, on the one hand, and the environmental limits to growth, on the other hand, will, more than ever, require small and medium-sized enterprises to adapt rapidly. This chapter deals with the challenges enterprises will face with regard to ecology in order to be able to manage in the future.

2.2 Limits to Ecological Capacity

Capacity of ecosystems

Nowadays, it can hardly be denied that industrial management has reached the principal limits of natural systems. Because of the decline in material resources and the concurrent steady increase in consumption, we will be faced in the 21st century with a shortage of essential raw materials (Fig. 2.1). The destruction of tropical forests, soil degradation of arable land and the over-fishing of the oceans show that even renewable resources are being used beyond what they are able to provide (Ewen 1994, p. 8). It is slowly becoming clear that the capacity of ecosystems to absorb harmful substances is limited and that, in fact, we will be confronted with this problem much sooner than with the shortage of exploitable raw materials. For quite some time, regional environmental effects such as acid rain, soil acidification and nitrification of surface and groundwater have been pointing that way. Considering the damage to the ozone layer and the

threat of the greenhouse effect, the global dimensions of the introduction of substances to the environment by human hand are finally becoming more and more apparent.

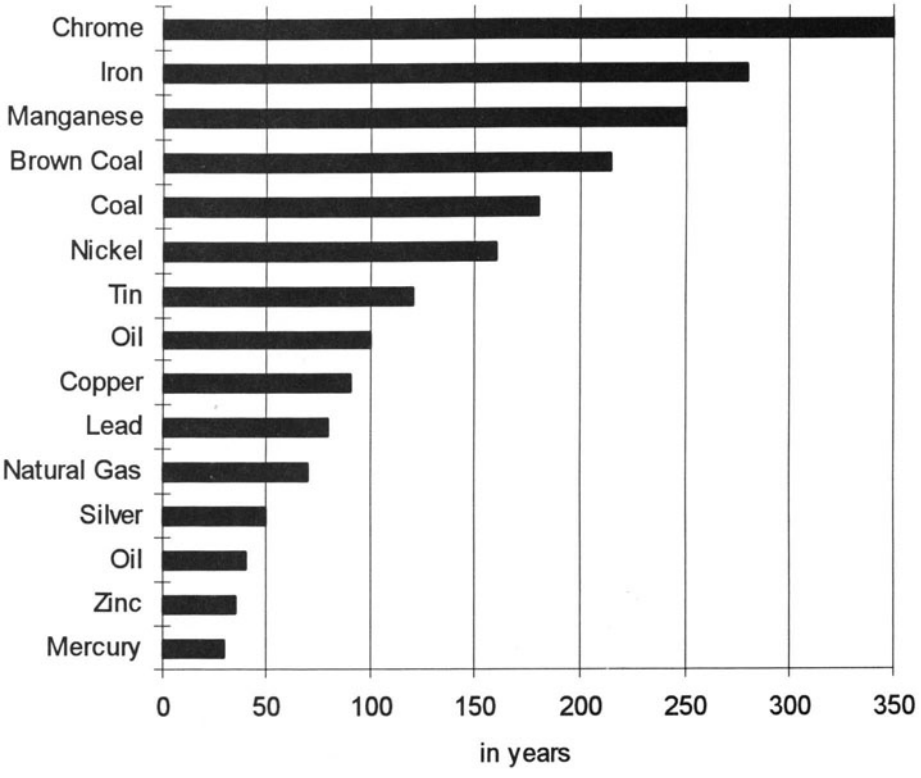


Fig. 2.1. Shortage of raw materials in the 21st century. (Baratta 1995)

'The Global Revolution'

The Club of Rome, an international group of well-known scientists, pointed out the limits to growth as a result of the exponential increase in population, exploitation of resources and destruction of the environment as early as the 1970s. The latest report from the Club of Rome, which was published under the title 'The Global Revolution', also concludes that the human race is rapidly heading towards its own destruction and that of the planet as a result of the exploitation of nature out of greed for material gain.

Greenhouse effect

This should not be considered as a dramatization of the situation. Rather, it is based on knowledge of the situation in a global context. The greenhouse effect is a representation of this and presents an area of prime concern. If the emissions that have climatic effects increase, which is very likely unless principal changes occur, then a global climate change will be inevitable. The probable consequences are difficult to predict and will vary from region to region. It is, however, quite certain that in most parts of

the world there will be extensive flooding, increasing numbers of hurricanes and declining harvest yields.

Although climate warming is a global phenomenon, the industrial states are mainly responsible for the situation. Although only 20% of the world's population live in industrial nations, they create 80% of its carbon dioxide emissions. If the western-type economy and affluent society were transferred to the poorer nations - which is a declared objective of these nations - we would require four more globes such as planet Earth to avoid an environmental collapse. If the present development were to continue, the carbon dioxide emissions would be eight times higher than today, thus requiring forty globes.

Forty globes

There is a similar development with regard to the flow of resources. In the industrialized states with 800 million people, 20 billion tons of materials are used annually (energy sources, stones/earth, ores, salts and biotic substances - disregarding overburden, excavated material, water and air). If we were to transfer this consumption of materials to the world population in the year 2040 (about 15 billion people), we would not only arrive at the gigantic figure of 300 billion tons annually but would reach a similar quantity for the flow of transport and harmful substances. The annual accumulation would be too much for the biosphere to absorb even before the middle of the next century (Meadows 1992).

Consumption of materials

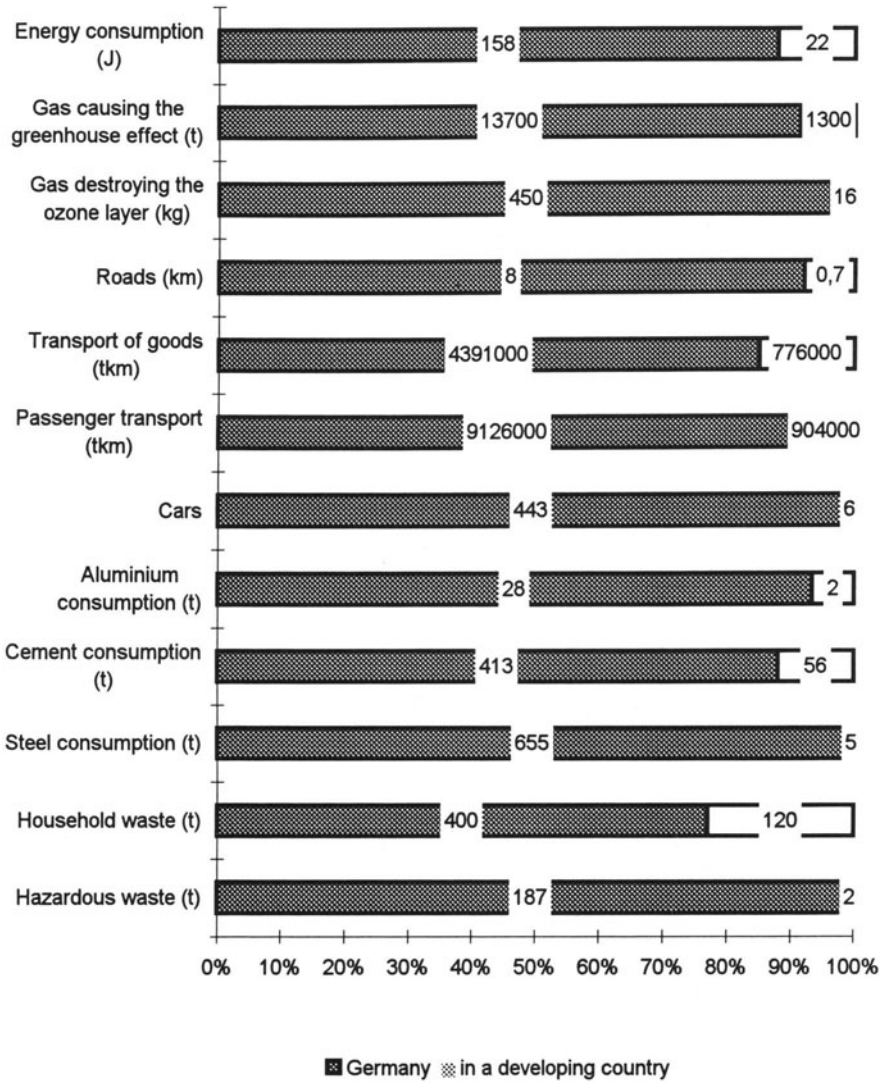


Fig. 2.2. Disparities in the consumption of resources and strain on the environment per 1000 persons between Germany and developing countries. (Wuppertal-Institut 1995)

The examples given show that unlimited growth in a limited world is not possible. We cannot go on as we have so far, with an increasing world population and ever increasing disparities between industrial and developing nations. Already today, the prevailing model of economic management as well as the model of an affluent society geared towards material gain are environmentally not sustainable and are certainly not suited as models for the future.

2.3 Sustainability as a Guiding Principle for Economic Management

'Brundtland Report'

In the long-run, sustainable development is the only answer for the future as already demanded in the 'Brundtland Report' by the United Nations World Commission for the Environment and Development in 1987. This means that the use of resources and of nature should harmonize with people's needs worldwide, now and in the future. The aim is not to reduce the natural 'capital' but rather to live off its 'interest'.

In forestry, sustainability has a long tradition. After the forests were nearly depleted in the Middle Ages, their use was established in order to ensure that not more wood was cut down than could grow again.

Declaration of Rio
Agenda 21

Today, sustainability is an accepted guiding principle in environmental politics and economic management. At the 1992 World Conference on Environment and Development in Rio de Janeiro, the principle of sustainability was the focal point of all discussions. The documents approved at the conference were the so-called Declaration of Rio and 'Agenda 21'. The latter contains an extensive sustainable development action programme, to which the signatory nations have committed themselves. After the conference, the European Union (EU) presented a programme for environmental politics and measures to be taken concerning sustainable and environmental development.

EU Programme

This programme deals with central environmental issues such as climate changes, acidification, water pollution, soil deterioration, shortage of landfill sites etc. Its strategy is not to concentrate only on these problems but rather to investigate a new interplay between the main groups of actors (government, enterprises and the public) and the most important economic sectors (industry, energy, traffic, agriculture and tourism) by using an extended and integrated number of tools.

Long run objectives are given for the individual sectors providing an orientation to enterprises for sustainable development. In addition, targets are defined which are to be realized within given periods up to the year 2000. Table 2.1 shows the objects and targets with regard to life cycle design.

Table 2.1. European Union Programme for environmental politics and measures (European Community Programme 1993)

Waste management for houshold waste			
Objectives	EU targets until the year 2000	Actions	Time frame
General objective: Efficient and sustainable use of resources			
• Waste prevention • Extensive recycling /reuse of materials • Safe disposal of waste which cannot be recycled or reused, with the following priority: 1. use as fuel 2. incineration 3. dumping on a landfill site	• Plans of member states regarding waste management • Freezing of waste products at 300 kg per capita on EU average (as in 1985): this value should not be exceeded by any of the member states • Recycling/reuse of paper, glass, and plastics with a share of at least 50 % (EU average) • Union-wide infrastructure for safe collection, separation and disposal • No export outside the union for permanent disposal • Recycling/reuse of consumer goods • Market for recovered materials • Noticeable reduction of dioxin emissions (reduction of the 1985 value by 90 % by 2005)	• Adoption of the directive regarding dumping • Adoption of directive regarding packaging • Clean technologies and product-design • Strategy for treatment of waste streams which should be given priority, stop dumping certain types of waste (legal regulations and voluntary agreements) • Reliable EU data on waste production, collection and disposal • System of liability • Economic incentives and tools (incl. disposal and return flow systems and voluntary agreements) • Standards for dioxin emissions due to incineration of household waste	Before 1995 1995 Continuous 1995 1995 2000 Continuous Before 1994

Table 2.2. EU Programme for environmental politics and measures (European Community Programme 1993)

Waste management for hazardous waste			
Objectives	EU targets until the year 2000	Actions	Time frame
• General objective: Efficient and sustainable use of resources			
• Waste prevention • Extensive recycling /reuse of materials • Safe disposal of waste which cannot be recycled or reused, with the following priority: 1. Use as a fuel 2. Incineration 3. Dumping on a landfill site	• No export outside the union for permanent disposal • Plans of member states regarding waste management • Recycling/reuse of consumer goods • Union-wide infrastructure for safe collection, separation and disposal • Market for recovered materials	• Adoption of directive regarding dumping • Adoption of directive regarding incineration of hazardous waste • Strategy for treatment of waste streams which should be given priority, stopping of dumping of certain types of waste • Clean technologies • Reliable EU data on waste production, collection and disposal • Creation of waste markets • System of liability • Stock-taking of risks • Economic incentives and tools (incl. voluntary agreements)	Before 1995 1995 Continuous Continuous 1995 Before 1995 2000 1995 Continuous

Certain segments of industry and commerce are also committed to the guiding principle of sustainable development. In April 1991, the International Chamber of Commerce (ICC) passed the 'Business Charter for Sustainable Development' at the 'Second World Conference on Environmental Management', joined by over 600 enterprises worldwide so far. Preceding the Rio Conference, the 'Business Council for Sustainable Development (BCSD)' was formed by about 50 enterprises committed to sustainable management.

Business Charter for Sustainable Development

In the wake of the international discussions, the guiding principle was defined more clearly. Accordingly, the following guidelines were outlined:

1. Nonrenewable resources should be used in such a way that total consumption will decrease even during periods of economic growth through increased resource efficiency.
2. Renewable resources are to be used to a greater extent without, however, exceeding the rate of regeneration.
3. The amount of harmful substances released into the environment should not exceed the absorption capacity of the ecosystem concerned.
4. The application of such technologies and products for which the environmental consequences cannot be foreseen and which could cause irrevocable damage should be avoided.

'Sustainable Netherlands'

Specific calculations as to the proportions of material and energy flows as well as the consumption of water and the use of land were made, for the first time, in 1992 by the Dutch section of the environmental group 'Friends of the Earth' in the action plan 'Sustainable Netherlands' (van Brakel 1993). Going on the assumption that every world citizen has the right to an equal share of the total amount of resources available in the world, i.e. the right to an equal share of environmental space, the study presented the following conclusions:

- In order to limit the temperature rise to 0.1 °C, worldwide CO_2 emissions need to be reduced by 1 - 2% a year. Dividing the maximum CO_2 emissions on a proportional basis, this means that the CO_2 emissions in the Netherlands between 1992 and 2010 must be reduced by 60%. By 2030, a further reduction of 60% will be required.
- With regard to drinking water which is available only on a regional basis, sustainable management in the Netherlands will lead to a reduction of the present level of water consumption by 32%.
- Nonrenewable resources must be reused by means of recycling in the long-run. The use of metals must remain constant or even be reduced. The worldwide use of aluminium, for instance, must be reduced from an average of 3.3 to 2 kg per world citizen annually. For the Netherlands, this means a reduction from the present use of more than 80%.
- Adapting agriculture to sustainable production systems would mean that 0.25 ha of crop-land are available per world citizen, of which 0.19 ha are required for basic dietary needs. In comparison: at present, 0.45 ha are available per citizen in the Netherlands. Meat consumption must be reduced by 60 - 80%.

- In order to maintain the ecological capacity of the forests, a maximum of 0.4 m^3 of timber per person per year would be available worldwide. The Netherlands, a country with few forests and a high consumption of timber, must reduce its present use of timber by 60%.
- Unlimited mobility will no longer be possible in the year 2010, even with sustainable development. In principle, 1 litre of fuel per day will be available per world citizen. A citizen of The Netherlands would have to decide, for example, whether he or she would prefer to travel 25 km by car, 50 km by bus, 65 km by train or 10 km by plane. A flight from Amsterdam to Rio de Janeiro would, under these circumstances, be possible only once every 20 years.

Sustainable Germany/Norway

Comparable studies have been carried out for Germany and Norway (Wuppertal-Institut 1995). These studies also point out the grave changes and cuts which are required in both the economy and society if sustainable development is to be put into practice (Table 2.3).

It is necessary to change from high consumption and a wasteful lifestyle to a more modest and slower way of living. By no means does this mean asceticism or total denial, but rather the development of a new understanding of affluence, encompassing durability of a product, a change in consumer behaviour and the joint use of products.

In economic terms, the principle of sustainability means that economic growth must be decoupled from the development of environmental degradation. That way, at least partial solutions to the problem of the long run sustainability of nature can be found in reasonably short periods of time. This requires far-reaching steps which can be summarized by three complementary challenges for enterprises: the efficiency, consistency and sufficiency challenges.

Table 2.3. Objectives in environmental politics for a sustainable Germany. (Wuppertal-Institut, 1995)

Environmental indicator	Medium-term environmental objective	Long-term environmental objective
	Extraction of resources	
Energy		
Primary energy consumption	At least - 30 %	At least - 50 %
Fossil fuels	- 25 %	- 80 - 90 %
Nuclear energy	- 100 %	
Renewable energies	+ 3-5 % per year	
Energy productivity [a]	+ 3-5 % per year [c]	
Material		
Non-renewable raw materials	- 25%	- 80 - 90 %
Material productivity [b]	+ 4-6 % per year	
Area		
Populated area and traffic area	Absolute stabilization annual new development: -100 %	
Agriculture	Complete conversion to ecological farming. Regionalization of nutritional cycles	
Forestry	Complete conversion to forestry close to nature Increased use of native wood	
	Emissions	
Carbon dioxide (CO2)	- 35 %	- 80 - 90 %
Sulphur dioxide (SO2)	- 80 - 90 %	
Nitrogen oxide (NOx)	- 80 % by 2005	
Ammonia (NH3)	- 80 - 90 %	
Volatile organic compounds (VOC)	- 80 % by 2005	
Synthetic nitrogen Fertilizer	- 100 %	
Biocides in agriculture	- 100 %	
Erosion of soil	- 80 - 90 %	

a) Primary energy consumption related to the value-added, gross domestic product.

b) Consumption of nonrenewable primary materials related to the value-added.

c) With annual growth of the gross domestic product of 2,5 %. It must be pointed out, however, that the long-term environmental objectives cannot be achieved with continuous growth.

2.4 Challenges

Increasing resource use efficiency: Sustainability is achieved through more efficient use of materials and energy, i.e. by using fewer resources per product and per production output. In that way, the consumption of resources and the burden on the environment could be reduced in relative and absolute terms, if there is no growth. Ways and means to achieve this are to be found, among other methods, through technical optimization, for example, by increasing the degree of efficiency in thermal processes.

The actual challenge for the future, however, lies in the design of products that have a long life span and in the organization of a circular economy. Products and materials should, if economically feasible, be used as long and as often as possible before their material content is reused and reprocessed any further. Thus, resources can be conserved, and emissions and waste reduced.

If the quality of materials used in a product could be reduced by half and if the product life and recycling rates could be doubled at the same time, this would result in an increase in resource efficiency by almost a factor of 10. It would present a revolution in efficiency. Such an increase over several years in the productivity of resources, analogous to the historic increase in work efficiency, would be quite realistic for certain material flows (Huber 1995, p. 135).

It must be taken into account, however, that the increase in efficiency can be, at best, a basic strategy on the way to sustainability. There are limits to the complete recycling of the original materials, such as wear and tear, friction and corrosion of certain products (brake linings, luminous coatings, clothes etc.). The return of products is faced with technical, organizational and economic limits because of their dissipation to millions of consumers. Finally, recycling causes a deterioration in material quality. Therefore, primary raw materials have to be added in varying quantities. Material cycles do not constitute - assuming an unlimited supply of energy - a perpetuum mobile.

Forming consistent material flows: Efficient products are necessary but not sufficient to fulfil the principles of sustainability (Huber 1995, p. 131). A further challenge consists of adapting material flows to bio-geochemical material cycles. This means that anthropogenic material flows, if they cannot be kept safe in closed technical cycles, must be integrated into ecological transformation processes. The goal is to replace critical materials and processes with other, less problematic ones.

One example is the replacement of CFC compounds used for metal degreasing, with materials that are less harmful to the ozone layer such as solvents made from chlorinated hydrocarbons. It would be even better to

avoid such materials altogether and use comparatively harmless hydrocarbons instead. In the field of packaging, harmful PVC could be replaced with unproblematic polyolefines. Critical energy sources such as brown coal could be replaced by less critical ones such as natural gas. A further step would be the substitution of regenerative forms of energy such as solar, wind and geothermal energy or energy-carriers based on hydrogen for fossil fuels.

Efficiency and consistency strategies must complement each other. With computers, for example, material flows could be reduced by lengthening the product life cycle. In the long run and as quantities accumulate, these flows will continue to constitute a problem (Huber 1995, p. 139). This is particularly true if the number of computers continues to increase. If computers and their components were designed and made with fewer harmful substances, most of the negative effects of material flows on the environment could be avoided.

Sufficiency challenge: Sufficiency means meeting needs modestly. It is not so much a question of renouncing certain needs but rather the importance of evaluating how these needs are met. This includes selling the use of a product rather than the product itself. A room can be heated by using energy from a power plant but also by means of insulation and the use of solar energy. This idea has been applied in the USA since the 1970s in the form of so-called energy services. In the Netherlands, Germany and Denmark similar service concepts are also being developed.

These services are created by energy supply enterprises which inform customers of methods of saving energy and economical energy consumption. They are offered suitable technical facilities (thermal insulation, effective energy technology, heat recovery etc.). As a result, the energy supplier delivers less energy and, at a certain level of energy saving, less power plant capacity is required, which saves costs.

The principle of selling a service rather than a product can also be applied to other product groups. In this connection ecoleasing should be mentioned. The manufacturer remains in possession of the products and is responsible for the maintenance, repair, refurbishment and upgrading of the products as well as their disposal. In this way, an economic interest is stimulated in designing products that are easy to repair and have a long life span. Currently, printers, copiers, computers, medical appliances and chemical solvents (rent-a-chemical) are being offered in this way.

In the long run, new user concepts such as ecoleasing, but also the joint use of appliances by product sharing, are essential to a basic structural change in the direction of a sustainable economy. For the manufacturers, however, this means that an industry that now uses primary raw materials will change into an industry that uses secondary raw materials. The

chemical industry will turn into a chemical service industry. The car industry will offer mobility services and the building industry will be primarily concerned with the life time maintenance and extension of existing buildings (Ewen 1994, p.10).

3 New Framework

Life cycle design is the design of products and processes that encompasses the entire life cycle of a product: from raw material extraction and processing to the production, distribution, use and return of materials to the industrial cycle or their disposal. The main objectives are to prevent and reduce material and energy input, material diversity and the use of hazardous substances. Life cycle design is based on the fundamental assumption that these measures will decrease the burden on the environment.

Recycling

3.1 New Instruments

For many years environmental protection meant pollution control. The concept of improved environmental performance did not appear until the 1970s, when the awareness and influence of the consumer increased. The market share of environmentally oriented consumers rose steadily as well as their representation as NGOs (Non-Governmental Organizations) on decision-making boards. Customers demanded detailed product, emission and site information.

Another, more recent, development was the growing uneasiness about ever stricter emission permits combined with a lack of enforcement and control in many countries. In environmental sciences, new instruments for impact assessment were developed and applied. Thus, the time was right for a new approach to product stewardship, combined with new environmental policy instruments. This new product responsibility created a challenge especially for product-design: its whole environmental life cycle had to be considered.

These various new influences on life cycle design are shown in Fig. 3.1.

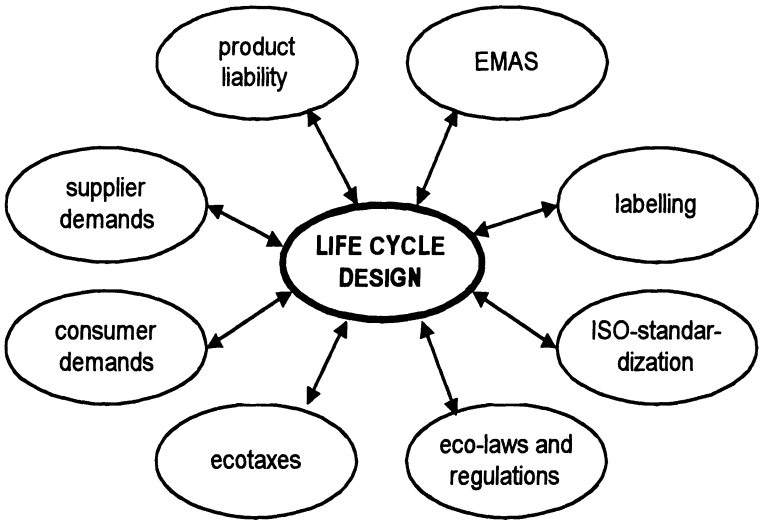


Fig. 3.1. New influences on product design

In connection with stricter product and environmental liability laws in the 1980s, companies in the United States and the United Kingdom started to make periodic reviews of environmentally relevant parts of their products and processes and to monitor compliance with legal requirements. The tools used for this purpose are a mixture of scientific environmental evaluation methodologies, internal controlling and auditing procedures, adapted in such a way as to put new emphasis on assessing a company's environmental performance.

New instruments were developed which rely on the self-regulating forces of the market and the economy as well as on the responsible behaviour of organizations and consumers. The aim of these market-based instruments is to provide an appropriate framework for organizations to take economic and environmental responsibility for their activities, thus making environmental management and ecologically responsible business practices financially attractive - not only for the economy as a whole but also for the individual organization. These so-called soft incentive instruments are meant to provide incentives rather than punishment.

3.2 Environmental Management and Audit Scheme of the European Union

EMAS

One of the most important instruments of the European Union is the statement of participation under its voluntary Environmental Management and Auditing Scheme (EMAS). This new instrument clearly embodies the idea of preventive environmental policy. Companies that want to participate must assess the environmental impact of their products, processes and services. The result should consist of detailed quantified targets and a programme for pollution prevention.

They then install a management system to audit their performance and legal compliance regularly. The participating industries publish an environmental statement that has been validated by an environmental verifier. The statement of participation awarded by the European Union shows the EU stars combined with a text stating that an environmental management system has been installed at the site.

The objective of EMAS is to promote continuous improvements in the environmental performance of industry by:

1. The establishment and implementation of environmental policies, programmes and management systems by companies, relative to their sites.
2. The systematic, objective and periodic evaluation of the performance of such elements (internal audits and validation by an independent verifier).
3. The provision of information to the public (statement) on environmental performance.

In this context, it should be mentioned that the EMAS regulation does not prescribe certain emission limits as minimum standards, but opts for a dynamic instrument to proceed on the road towards sustainable development. In their environmental policy, participating companies must commit themselves to compliance with all relevant regulatory requirements regarding the environment as well as to reasonable continuous improvements of their environmental performance.

These commitments must lead to a reduction in environmental impact through the economically viable application of the best technology available. Another obligation is the application of so-called good management practices which describe preventive organizational measures for reducing environmental impact at the source. In light of the results of the environmental review and of subsequent audits, companies furthermore must define targets (largely quantitative) for all their departments, the fulfilment of which must be reviewed in the next period.

In the review and audit, the environmental performance as well as the risk potential of the site, its processes, services and products are assessed. This implies an evaluation not only of site emissions and risk factors, but also of material purchase and products. It is not a prerequisite to undertake a detailed product life cycle assessment, but product-design is explicitly mentioned as an area for improvement in better environmental quality.

3.3 Ecolabelling

Blue Angel EU

The ecolabelling scheme for products is the other product-oriented environmental policy instrument of the European Union. In Germany, the Blue Angel appeared in 1977 as a product award, granted by the German Environmental Protection Agency. At that time, the Blue Angel focused on one specific product characteristic, but also aimed at a comprehensive evaluation of the product life cycle.

Ecolabel

In March 1992, the Commission of the European Union announced its regulation on a community system on ecolabelling. Regulation 880/92 is a voluntary instrument resulting in the award of a label on products in the shape of a flower (Fig. 3.2).

Fig. 3.2. The EU ecolabel

These products are characterized by a significantly lower environmental impact during their entire life cycle than that of competitive products which fulfil the same functions. The aim of the regulation is to stimulate

the design, processing and use of environmentally-friendly products that have been processed by resource-efficient and cleaner technologies.

Washing machines

For the environmental impact assessment of those products an indicative assessment matrix has been developed which shows the product life cycle and the environmental fields to be assessed (Table 3.1). The leading countries are responsible for the development of indicators that define the quantitative and qualitative criteria to be fulfilled. For washing machines, for instance, this includes optimal use of energy and water and other requirements. Some companies also use this assessment matrix for the internal identification of improvement options.

Table 3.1. EU Indicative Assessment Matrix

Environmental fields	Product life cycle				
	Pre-Production	Production	Distribution (incl. packaging)	Util-ization	Disposal
Waste relevance					
Soil pollution and degradation					
Water contamination					
Air contamination					
Noise					
Consumption of energy					
Consumption of natural resources					
Effects on ecosystems					

3.4 ISO Standardization

Environmental management is a top-priority issue, not only in the European Union but worldwide.

Since 1993, several subcommittees and work groups of the Technical Committee TC 207 within the International Standardization Organization (ISO) have been developing a new series of standards called 'ISO 14000'. In the near future, the following methodologies will be covered by worldwide standards:

- Environmental management systems.
- Environmental auditing.
- Environmental performance evaluation of sites and organizations.
- Life cycle assessment of products.

ISO guide

Furthermore, there is an ISO guide on 'Environmental Aspects in Product Development', aimed at all standardization bodies, to ensure that environmental criteria are considered in standardization procedures. This guide was drafted under the chairmanship of Germany and reflects the guidelines on product-design by the German Verein Deutscher Ingenieure (VDI). Especially in Germany, but also within the European Union, there are several guidelines and directives on product-design and classification.

VDI guide lines

Within the standard-setting bodies, the influence of environmental scientists, consultants and consumer representatives is growing constantly. Under the new approach of the European Union, standards define the content and interpretation of regulations. Therefore, to be represented in the standard-setting bodies is currently of key importance to all interested groups.

VDI 2243

Up to now there have been comparatively few standards on ecodesign that are helpful in the design process. One of them has been developed by the German standardization organization DIN and is called DIN 54840; another is VDI 2243. The guidelines of the VDI were drafted in 1984. In October 1993 a final version was distributed that includes definitions, procedures and design guidelines, with a special emphasis on recycling possibilities (VDI 1993).

3.5 Environmental Laws and Regulations

Since the 1970s, the extent of environmental legislation has broadened steadily; its quality, however, has not increased. Enforcement and control are also quite weak. In many countries, environmental legislation is divided among several laws and it is quite difficult for an organization to find out with which laws it actually must comply.

„Kreislaufwirtschaftsgesetz“

In Germany, for instance, efforts are being made to realize integrated environmental legislation. The result is a comprehensive book called the 'Kreislaufwirtschaftsgesetz' (Closed Substance Cycles Act), which was to become effective in 1996.

Besides integration, one emphasis of this law is extensive waste management. As in other countries, such as Austria, German companies must come up with a waste-prevention plan as well as regularly monitor and report on their waste flow.

The main principles in German environmental management are the principle of prevention and the „polluter pays“ principle. The resulting responsibilities are product stewardship and take-back obligations. For example, several products will only be allowed on the market if recycling possibilities exist.

One current example is the take-back obligation for refrigerators. A general take-back obligation for consumer electronics has already been discussed for years. It has resulted in several research initiatives on product-design changes.

3.6 Ecotaxes

Ecotax

Ecotaxes are a standard agenda item in the policy discussions of the European Union and several European countries. Ecotaxes can be levied either on the material input or on the resulting output of products and emissions. The Nordic countries already apply several of them, especially taxes on the consumption of energy, water and some chemicals. Some emissions and wastes such as carbon dioxide, packaging and hazardous waste are taxed as well. For many years, the European Union has been considering a general tax on energy carriers.

With these environmental taxes, the costs of pollution are attributed to the polluter. Several public opinion polls indicate that these environmentally beneficial taxes are the only ones accepted by the consumer. Therefore, as

many countries have budget problems, it can be expected that their importance and share of the total tax revenue will increase.

The fees for garbage disposal can also be seen as a tax, attributing the garbage disposal costs to the generator of the waste. Due to high safety demands and their low public acceptance, these fees have risen steadily in the last few years.

Mandatory take-back fees for packaging exist in several countries, but also for more complex products such as refrigerators in Austria or cars in the Netherlands. For instance, as of December 1994 the Dutch Minister of Housing, Physical Planning and Environment has levied a deposit on cars. This tax, which amounts to 250 Dutch guilders per car, is charged whenever a new car is sold. The tax earnings are invested in specific disassembly processes of car demolition firms. An organization named 'Auto Recycling Nederland BV' was established to distribute the tax earnings to those demolition firms which are associated with this organization. The aim of the organization is that by the year 2000 at least 88 % of the weight of a car will be recycled. Therefore, one solution for tax prevention is ecodesign!

3.7 Consumer Demands

Power of consumers

The power of consumers in driving organizations towards environmentally responsible behaviour is a recent phenomenon. The worldwide boycott of Shell petrol was a consumer action which was not expected by top Shell management and politicians. There is a tendency for NGO's and non-organized consumers to increasingly use this enforcement instrument, e.g. against furs, frog legs, tropical wood, Norwegian fish and against French products in general because of nuclear testing by France.

In 1990, two thirds of the private European households described themselves as environmentally friendly shoppers. Their number is still increasing, with environmental awareness being particularly high among young educated women, especially those who have children.

"Shopping for the environment" began as an initiative of American environmental protection groups, who rated companies on a scale of ten criteria on their environmental policy and performance. The criteria also included animal testing and equal treatment of women.

Some European organizations such as the German 'Stiftung Warentest', rate companies and products according to life cycle design criteria and publish awards and documentation. Therefore, other organizations tend to focus their design criteria on those awards.

Cooperation between retailers and environmental groups has led to checks on the product range and to the replacement of some products.

In this context, environmentally oriented investment funds should be mentioned as well.

3.8 Supplier Demands

Green products (e.g. Chap. 10) benefit from the application of environmentally oriented purchasing criteria. A snowball effect can emerge, similar to the ISO 9000 series, where supplier audits are among the main reasons for the spurt of the standard application. The same can be expected with the new ISO 14001 standard on environmental management. Within the management system, together with supplier audits, purchasing guidelines that specify detailed product criteria for pollution prevention are to be defined and checked.

ISO 9000

ISO 14001

Many companies also force their suppliers into take-back obligations, not only for packaging but also for the whole product. Nowadays, office equipment can only be sold if the old furniture is taken back by the supplier. Thus, it makes sense to design these products in a way that actually allows reuse and recycling.

This demand completely changes the product-design. Ease of repair, modular design, easy disassembly, information on materials and their possible reuse are becoming increasingly important economic and marketing aspects.

3.9 Product Liability

Product liability is a strong issue in the USA, although the environment is not the main consideration. In Europe, the environmental liability of organizations is regulated but these regulations do not mainly deal with products.

As organizations produce products, it is likely that, in the future, the two instruments can and will be used jointly. The underlying principle is that the possible damage from a process or a product can make an organization liable, with the burden of proof being shifted towards the producer or the seller. Thus, it will be up to the organization to show that its product design is sound and that its use is not dangerous in any way.

Anticipating all these new instruments for environmental protection and considering that the time span from a good product idea to its appearance on the market may be years, an organization is well advised to adopt a proactive approach. The following chapters will highlight how this can be achieved.

4 Environmental Situation of Complex Products

4.1 Introduction

Industry is constantly working to improve its products and new products are put on the market all the time. Functionalism, quality, safety, design and low costs are the priority demands on a product. Increasingly, the environmental impact is also being considered as an important aspect of product-design.

New processes

Today, with the help of new polymerization processes and the use of additional materials, new plastics are being produced. Not only do they allow greater diversity with regard to design and in terms of surfaces but they also help to reduce product weights considerably and result in material savings.

Quantum leaps in the field of microelectronics have led to miniaturized constructions and electronically regulated control systems. With their help, a reduction in the energy consumption of electronic appliances has been possible. With regard to washing machines and dish washers, the consumption of water and chemicals has also been noticeably reduced.

Since waste disposal is becoming more of a problem every day, industry has begun to give thought in the design phase as to what will happen at the end of a product's life cycle. The present approaches in this regard are, however, limited to product disassembly, shredding of parts, selecting materials and reusing them.

Although some progress has been made, industry - including small to medium-sized enterprises - in many respects does not yet meet the requirements for environmentally friendly products. The weaknesses will be discussed in the following section.

4.2 Environmental Weaknesses of Complex Products

4.2.1 Shortening the Life Span of Products

A fundamental shortcoming of many products is that neither their absolute life span nor their full intensity of use are completely exploited. Increasingly, throw-away products are being developed which, by their very nature, lead to more demanding material and energy cycles. The pace at which old products are being replaced by new ones is accelerating all the time. This can be observed not only for packaging. Even with complex products the pace of replacement is so fast that, in some cases, the border line between durable goods and throw-away goods is disappearing altogether. A typical example is the disposable camera that is thrown away after using one film.

But there are also many other consumer goods which quickly lose their original value. The reasons for this are manifold. One of them is the pressure to remain cost-effective in a competitive market. Instead of expensive high-quality wood for furniture, cheap coated chipboard is used which, of course, has a much shorter life span. Electrical goods are sometimes equipped with components of inferior quality, such as seals, for example. As a result, signs of wear and tear emerge soon. For repairs, cost is the decisive factor. Many faulty products could easily be repaired but, as repair costs would be too high, they are replaced.

Innovation cycles

Another important reason contributing to the shortening of the product life span is that innovation cycles are also becoming shorter. As a result, products quickly become obsolete, although their technical life span has not been reached by any means. This is very often the case in the field of information and communication technology.

The innovation cycle of a personal computer (PC) is half a year. Computers of a new generation sometimes do not even get to the consumer. They are taken straight from the manufacturer or dealer to disposal (Deutsch 1994, p. 19), thus becoming "goods with zero usage" (Stahel 1991, p. 180).

Fashion

Fashion also contributes towards an increasing consumption of products such as cars, furniture and textiles, when the fashion of the previous year is labelled "out". With the Swatch watches this mechanism has been turned into a lifestyle. New watch designs are being generated all the time but the watches themselves can neither be taken apart nor are they recyclable. The worldwide success of the Swatch gives credit to this marketing strategy. It remains, however, questionable from an environmental point of view.

4.2.2 Product Designs that are Difficult to Disassemble or Recycle

The technical development of complex products has been accompanied so far by an increasing number of components or materials in any one product. The range of these materials, especially plastics, but also metals, ceramics and semiconductors, is constantly widening and the individual material compounds and material combinations are no longer separable. Often enough the producers themselves do not know what the characteristics of the materials are and in what combinations they have been used in the product.

Therefore, today's recycling methods quickly reach their limits. The marginal product improvements on which industry has been concentrating, such as a reduction in material variety, the use of connection elements that can easily be disassembled and the marking of plastics, have had only little effect.

With regard to the high expenditure in processing technology and energy consumption, there are serious shortcomings in today's recycling technology.

Complex construction: The large number of components and component groups as well as complicated connections which do not allow system parts to be separated without destruction (owing to welding, bonding or coating) make product disassembly uneconomical (Fig. 4.1).

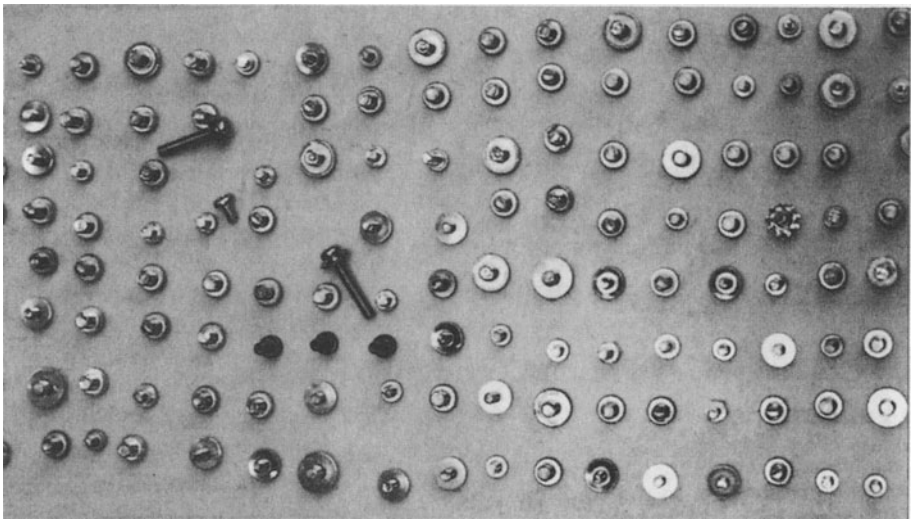


Fig. 4.1. Variety of screws used in computers. (Digital Equipment GmbH, München)

Materials: The vast variety of materials, the use of compounds, special tools and additives (flame retardants, stabilizers, softeners, biocides etc.) inhibit separation according to material groups. In addition, certain material compounds used in products are not compatible in recycling, especially if they are to undergo a mass stream process.

Spreading of harmful substances: Recycling processes exist for metals and for presorted plastics. Problematic substances and contamination lead to problems such as additional emissions during the recycling process, low quality of recycled materials and the introduction of harmful substances into products.

Composite constructions: Composite constructions and composite materials present a special problem. Today, it is possible to bind metals with plastics or ceramics in such a way that separation along the material boundaries is impossible or at least not economically viable.

Fibre composites - although highly rated because of their great strength, high elasticity and low weight - once used in composites are unsuitable for recycling.

Additives: Further problems are created by numerous improvements of system parts and materials for which a whole array of chemical additives is used. These include protection against corrosion, plastic coatings, paints, antistatics, biocides or doping materials which allow special functions and use of materials and system parts. Often these additives are particularly critical substances that cause serious problems with regard to reuse because of their physically and chemically complex attachment to the carrier substances.

Electronics: Electronics consist of a mixture of materials with a variety of chemical substances, often with a considerable potential for harm, which are therefore reusable to a limited extent only. Theoretically, only 2 - 3% of the components can be recycled. The material reuse of electronic components is restricted to the recovery of the metal fraction (copper, nonferrous metals, precious metals) in smelters. In addition, the decreasing share of precious metals in electronic elements is lowering the economic incentive for reuse. Regarding harmful substances in electronic scrap, special attention is paid to electrolytic capacitors, components containing mercury and in some cases liquid crystal displays. In Germany these components are dismantled manually and deposited underground.

Emissions during recycling: The recycling of materials can lead to emissions which have a negative influence on the environment. In order to recover copper or non-ferrous metals, for instance, the printed circuit boards are put into a converter. The plastics and organic materials are burnt, whereas the base metals are retained. The precious metals are then, using electrolytic copper refinement, recovered from the anodic sludge.

The metallurgic recovery of metals from electronic scrap leads to dioxin emissions which are no less than those during solid waste incineration. Responsible for these emissions are mainly PVC-coated capacitors, haloginated flame retardants in printed circuit boards and cased micro chips, as well as lacquer and paint remnants on electronic components.

Degradation of materials: Recycling processes usually cause degradation of the material concerned. The share of materials that can be returned to the original material flow at a high quality level is low.

Recycled plastics are, for example, used for making park benches, noise protection walls or bird-nesting boxes. Only one tenth of scrapped printed circuit boards is reused, two thirds of the original quantity turn into sludge. The glass from TV tubes is melted and then used as inert filling material for road and tunnel building or for the disposal of radio-active waste. This can no longer be termed recycling. It rather represents the redistribution in the environment of the flux that results from the downcycling of plastics, composite materials and scrap. This development may well, in the future, become as problematic as the past use of asbestos (Huber 1995, p. 147).

4.2.3 Insufficient Collection, Return and Reuse Logistics

One main drawback of recycling lies in the organization of the registration and collection of old appliances. A separation of these products from household and bulk waste does not make sense and is, at present, neither technically nor economically feasible. Suitable logistic systems which involve wide-spread registration do not yet exist. In this connection, a return obligation for various products is being discussed and prepared in Germany on the basis of the law on waste and the closed substance cycles economy. A regulation for electronic scrap is planned which aims to register electrotechnical and electronic household and office appliances.

In view of the expected legislative steps some manufacturers, such as IBM, Nokia and Grammer AG, have introduced return systems for their products. Retailers such as Quelle also take back certain appliances, e.g. refrigerators or television sets, for a fee. The return rates are, however, low. The figure for computers quoted by IBM is less than 1% of the new appliances delivered annually (Rhotert 1993). The situation is particularly difficult in the case of small appliances which, because of their size, are generally disposed of together with household waste.

4.2.4 Low Use of Renewable Resources

Because of the scarcity of nonrenewable resources, a gradual shift is taking place in favour of renewable resources.

The use of renewable materials so far concentrates mainly on wood for furniture or as building material, cellulose for paper production and other renewable resources such as cotton for textiles. A classic field for renewable materials is packaging, where there are many additional possibilities for starch products made from corn, potatoes or wheat. In the chemical industry, products have long been produced from renewable resources such as oils, fats, starches and sugars. Currently 10% of the materials used have an organic basis. This share could be increased to 20% if potential renewable resources were to be developed.

Complex products

The use of renewable resources in complex products in the field of consumer and capital goods is, however, comparatively low. Because of progress in the development of materials but also due to cost factors in the last decades, plastics have almost totally displaced traditional renewable materials. The use of wood, for example, is practically limited to the furniture industry.

Recently, possibilities for the use of renewable resources in complex products have been discovered. Robust composite materials can be made from hemp or flax. A frame made from natural fibres provides a robustness that is comparable to one made from plastics reinforced with glass fibre. A first application of these materials is intended in the car industry. Further fields of application in which bioplastics would be useful and environmentally beneficial are children's toys, furniture and ship and aeroplane building.

However, considerable problems for the environment could arise from growing and processing renewable raw materials. This applies wherever production results in intensive monocultures and the use of synthetic fertilizers and pesticides. The intensification of agriculture as well as monocultures contribute to erosion of the soil, pesticides and fertilizers contribute to water pollution. If the original advantages of renewable raw materials to the environment are to be emphasised (neutral with respect to carbon dioxides because biodegradable), then natural cultivation methods must be guaranteed. Furthermore, it must be pointed out that, in principle, there is also a shortage of renewable raw materials because arable land is limited and there is direct competition with food production. With the present level of production and consumption, one can assume that renewable raw materials will not, on the whole, gain a substantial share.

4.2.5 Potential Toxicity

Complex products contain a variety of chemical substances, many of which are potentially harmful to health and environment. Critical substances are flame retardant materials on a halogen basis or antimony trioxide, chlorofluorocarbons (CFCs), polyvinylchloride (PVC) and heavy metals.

Flame retardants

Flame retardants are used in printed circuit boards, cased-in microchips, cables and plastic casings, following safety regulations. But polybrominated flame retardants bring considerable risks when incinerated or burns in rubbish dumps, because under certain conditions highly toxic dioxins and furans can be formed. If a television set catches fire in a home, it is advisable to dispose of all the furniture as special waste. Since polybrominated flame retardants often become contaminated with dibenzodioxins and -furans in their production, it is possible that dioxins will be emitted during the normal use of a set. The pollution of the air in the room will, however, be low. The German Ministry of the Environment therefore does not consider it a direct danger. Anyhow, it should be kept in mind that these substances cannot be broken down by the human metabolism and accumulate in the body.

Polybrominated flame retardants

This material group is to be classified as particularly critical because of the following characteristics:

1. The polybrominated flame retardants used are highly toxic. They can harm the spleen, the liver, the eyes and the immune system; in animal tests decabromide and diphenylether proved to be carcinogenic.
2. Under strong thermal influences, for example during incineration or household fires, dioxins and furans are formed and released. The high persistency, the strong accumulating toxicity with a wide spectrum of effects and the carcinogenic effect of dioxins make them the most problematic substances with regard to the environment.
3. As an alternative to the halogen organic compounds, antimontrioxide is used (in connection with brominated flame retardants) in plastics where no transparency is required. However, based on animal tests, this organic flame retardant has also been considered carcinogenic.

PVC

PVC is one of the most controversial plastics. Especially the chlorine content, which in pure PVC lies at 57%, causes problems in production as well as disposal. The preproducts such as ethylenedichloride and vinylchloride as well as some of the by-products are considered to be carcinogenic. As the formation of polymers during the production of PVC is never a complete process, vinylchloride monomer will always remain in

the products as a contaminant. The behaviour of PVC in the case of fire is a special problem. Apart from hydrochloric acid, polychlorinated dibenzodioxins and furans are formed in the soot of fires or in incinerators.

CFCs Further critical substances are CFCs, which are harmful to the ozone layer. They are used in foam generators for the production of the porous plastics polyurethane, polystyrene or as cooling agents in refrigerators.

Among the heavy metals there are lead, cadmium and antimony, which are used as alloys in soft solders. Lead is a substantial component in TV tubes (up to 20%), where it serves to form a screen against electromagnetic radiation. Substances which are potentially dangerous to health and environment are also used in semiconductor materials.

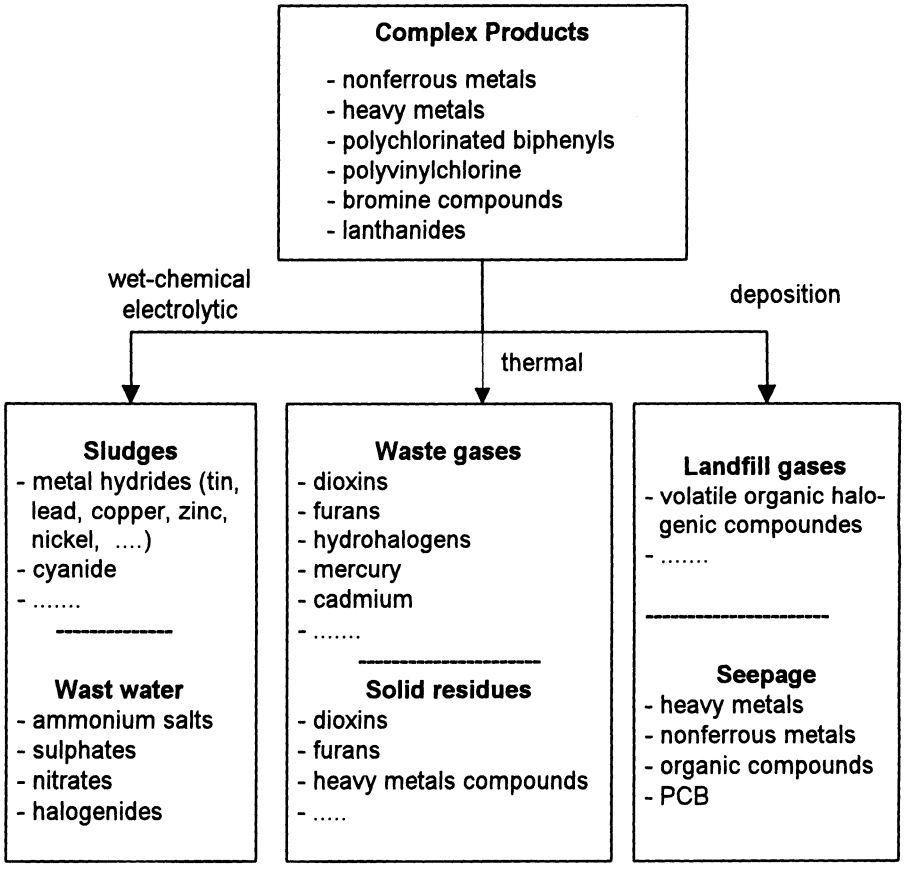


Fig. 4.2. Harmful-substance potential upon recycling of complex products. (Ewen 1993)

Table 4.1 shows the most important critical substances related to components.

Table 4.1. Substances in complex products that present a potential danger to health and environment

Materials	Occurrence
Antimony	Metal fillers (solders), plastic casings, pigment, doping material of microchips
Antimontrioxide	Printed circuit boards, cable, flame retardant in plastic casings, screens
Arsenic	Doping material of microchips, screens
Asbestos	Insulators
Barium	Screen glass (screens)
Beryllium	Screens
Lead (lead oxide)	Metal fillers (solders), material for electrodes in accumulators, screens
Flame retardants	Plastic parts in casings, printed circuit boards containing bromine, switches, plugs
Cadmium	Metal fillers (solders), plastic casings, accumulators, sheet metal with galvanic coating electrodes,
Cadmium compounds	Screens, semiconductors
Chrome	Resistors, conductors, screens
Chrome compounds	Screens
Chlorofluorocarbons	Plastic foam in insulating layers
Gallium and gallium compounds	Semiconductors
Germanium and germanium compounds	Semiconductors
Indiumantimonide	Semiconductors
Copper	Coils, transformers, cables, resistors, microchips, deflection unit (TV)
Copper compounds	Screens
Nickel	Plastic parts for casings, pigment, magnets, accumulators, resistors
Polychlorinated biphenyls	Dielectric in capacitors
Polyvinylchloride	Cable sheathing, casing parts
Mercury	Relays, mercury oxide and alkali manganese batteries, zinc coal batteries, fluorescent lights
Lanthanide sulphides	Luminous substances (screens)
Tantalum	Material for electrodes in accumulators, resistors, conductors, screens
Bismuth compounds (bismuth oxide)	Screens
Zinc	Material for electrodes in accumulators
Zinc sulphide	Fluorescent substance (screens)
Tin	Metal filler (solder), screens

4.2.6 Energy Consumption

Energy consumption is a central environmental factor. Many environmental effects such as the greenhouse effect, depletion of the ozone layer, acidification, noise, human and ecotoxic effects and the exhaustion of resources are more or less directly linked to power consumption.

Television

The energy consumption of a television set related to its life cycle adds up to a consumption of primary energy of 18000 MJ, of which 2000 MJ are used for the manufacture of the set and 16000 MJ for its use during a 12-year life span. Of the latter, 4570 MJ are used for energy consumed in stand-by mode. Related to all television sets in Germany, the power consumed in the stand-by mode alone would require the energy output of a medium-sized power plant. Even more marked is the relation between normal use and that of the stand-by mode for video recorders. The energy consumption of the stand-by mode at 9.36 kWh is 15 times higher than that for the actual use of the recorder at 0.61 kWh per month. This 'silent' consumption, which is on the increase with other appliances as well, is a waste of valuable energy and puts an unnecessary burden upon the environment.

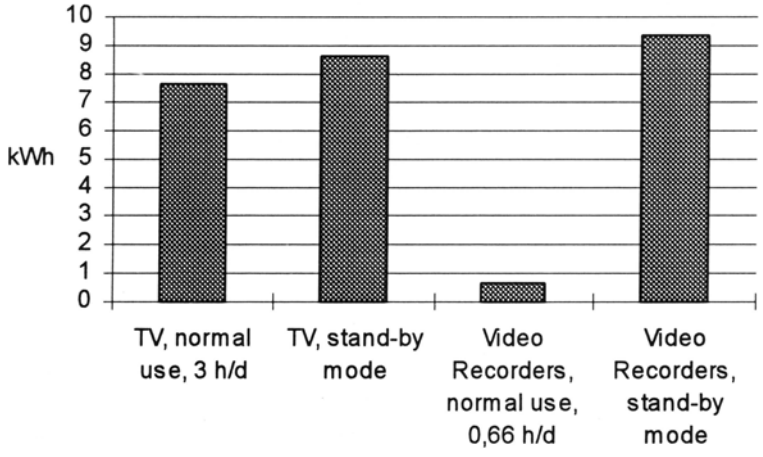


Fig. 4.3. Energy consumption of TVs and video recorders. (Neckarwerke 1994)

4.2.7 Disposal Situation

Since complex products of current design and composition are hardly suitable for recycling, they are disposed of either by incineration or dumping at landfill sites. Only 10% of all electrotechnical consumer and ca-

pital goods are recycled. Dumping of complex products generally involves mixing and compressing on a more or less permeable ground. In due course, leaching processes can dislocate substances that are harmful to the environment from the dumping site. For this reason, waste dumping, as a final option, should no longer occur without prior treatment.

To that end, thermal processes, for example, are used which aim not only at reducing the volume and weight of residual solid waste, but also at dealing with problematic substances by separating and destroying them or by making them inert. During such processes, however, volatile heavy metal vapours, dusts and organic compounds can be emitted by the incineration plant. In addition, on incineration of plastics with polybrominated flame retardants, dioxins and furans can be formed. PVC from cable sheathing can lead to the formation of hydrochloric acid and can also contribute to the formation of haloginated dioxins (Fig. 4.2, p. 38). Although the situation with regard to emissions from waste-incineration plants has improved considerably over the last few years, residual emissions can hardly be avoided. Furthermore, highly problematic residues result from the removal of flue gas, which must be treated as special waste.

Considering that in Europe there are 7 to 10 million tons of electrotechnical appliances which are disposed of annually, this situation - apart from the destruction of valuable materials - contributes to a further aggravation of the waste-disposal problem.

5 The Process

5.1 Introduction

This chapter deals with the way in which life cycle design (LCD) can be implemented in the product-design process of companies. Due to rapid technological innovation and heavy competition between companies, the economic life of many complex products has been shortened. In day-to-day practice this has led to short innovation cycles in which designers and constructors must balance hundreds of detailed product specifications. The innovation cycle of personal computers, for example, has been reduced to six months. Under these circumstances the successful introduction of LCD initiatives requires good organization, the smooth integration of environmental requirements into the design process and tools which readily deliver up-to-date environmental information.

As LCD must be integrated into the design culture of a company, organizational aspects are critical to its success (Shelton 1995). In Section 5.2 the involvement of internal and external stakeholders is discussed.

Normally LCD would not significantly lengthen the product commercialization cycle. LCD can therefore be woven seamlessly into the product-design process of a company. In Section 5.3 the integration of environmental considerations into design activities is presented.

Finally designers should have easy access to environmental information, enabling them to determine the environmental consequences of their design choices and to generate innovative ideas. This requires systematic tools which are adapted to the specific characteristics of complex products and which can offer the required environmental information. Section 5.3. outlines the assessment and improvement tools which can be applied in LCD. The exact formulation of the 'basic' tools, namely the environmental principles and criteria in combination with the ABC prioritisation tool, is explained in Chapter 6. In Chapter 8 some assessment tools for LCD are presented.

5.2 Stakeholders for Life Cycle Design

The evaluation of life cycle design pilot projects (te Riele 1994) has revealed that, for a successful introduction, a wide spectrum of stakeholders should be involved. These stakeholders can be grouped into three levels according to the importance of their involvement, as shown in Fig. 5.1.

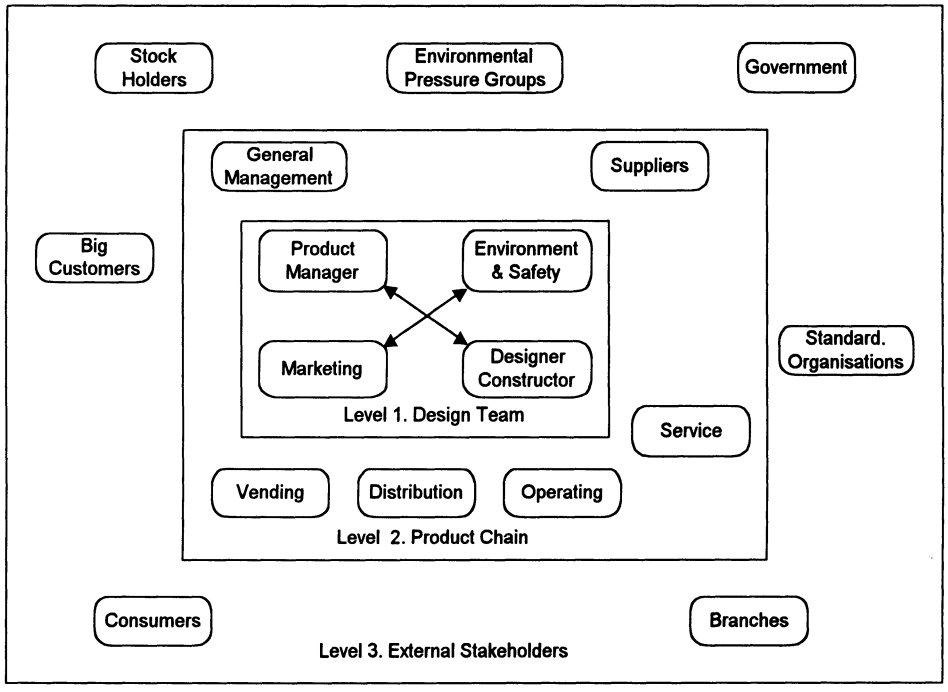


Fig. 5.1. Stakeholders for life cycle design

Level 1: The Design Team

The main task of a company is to deliver products for specific markets with the help of a limited set of technologies. Within this setting the most important stakeholders for life cycle design can be found in the design team (te Riele 1994).

LCD activities should be undertaken by the design team, a cross-functional team which involves at least four important groups: designers/ constructors, product managers, marketing staff and environment and safety experts.

The direct involvement of designers/constructors is critical for the practical integration of LCD requirements into the total set of requirements: they can only learn about LCD by doing. At the beginning of an LCD programme in a company, engineers will often not be aware of the environmental burdens associated with their products. Without proper

preparation they may be reluctant to consider a set of further requirements for their complex products. The design team should be supported by the company in the process of searching for environmental product innovations.

Therefore, the successful introduction of LCD depends on the commitment of product managers (Keoleian 1993). The integration of LCD as a real business consideration requires cultural changes which can be reached by clearly stated environmental product strategies laid down by the management. The product manager should ensure that these general product strategies are applied in the environmental requirements for a specific product line.

The marketing group can shape the environmental product strategy in such a way that more competitive environmentally sound products will be developed. Therefore, the environmental and other preferences of consumers should be determined on the basis of market surveys and other sources. By performing these needs analyses, the environmental and other market characteristics of the product can be defined, such as environmental performance, price levels, customer profiles and marketable quantities.

Finally, it is the task of the environmental and safety staff (E&S) to help the design team formulate realistic environmental requirements that can be incorporated into the total set of requirements. E&S staff should provide designers with the 'broad picture' of potential environmental opportunities and a framework for the company's product strategy.

Level 2: The Product Chain

In most cases there is a great deal of interweaving with other firms in the product chain (Crul 1994). In order to re-integrate the environmental aspects of the whole product chain, these other stakeholders should be involved, especially those whose decisions influence the design and application of products. This includes people from production, operation, accounting, distribution, packaging, and supply. Especially suppliers should be involved in environmental programmes, because partnerships with good suppliers enable the firm to obtain environmentally sound components and materials.

Level 3: External Stakeholders

Increasingly, the expectations of customers and stockholders are affecting companies' operations. Neighbourhoods are demanding cleaner sites and governmental environmental regulations and professional environmental standards such as ISO 14000 and BS7750 are driving companies to assess and reduce their impacts upon the environment. Ideally the design team should be aware of customers', stakeholders' and the government's

environmental concerns throughout the product life cycle.

Regulations for electronic waste

In order to stimulate LCD, businesses need long run regulatory guidance (Crul 1994). The development of German governmental regulations in recycling electronic waste (Elektronikschrottverordnung) was an important incentive for the Digital Company to start research focused on the recycling-oriented design of computer systems. The involvement of stakeholders from outside the company, such as suppliers and the recycling industry, was crucial for the development of these systems.

5.3 Tools for the Design Process

Although design processes are ultimately company-specific, there are some general features. In theory, an optimal design process starts, in the case of a new product line, with the definition of needs and the associated functions. It then proceeds through the formulation of requirements, conceptual design, detailed design and production. The design team makes the required choices during an iterative process of identifying alternatives (divergence), followed by the analysis and ranking of these alternatives (convergence). Gradually, the scope for feasible alternatives is restricted as the team tries to meet all design specifications for the final product-design.

In this design process various stages can be distinguished. For LCD, three main stages are considered: product strategy, product formulation and product specification. At the stage of product strategy for a new product range, the reformulation of functions, new features and technologies are considered. This stage requires the 'broad picture' of potential environmental opportunities and a framework for the company's product strategy. The range of possible alternatives is relatively broad at this stage. During product formulation, the general design of a specific product is determined on the basis of the product requirements. At the stage of product specification, the designers and constructors are concerned with the practical preparations for manufacture by formulating details of the parts and materials (Fig. 5.2.).

In order to make choices between design alternatives, a number of so-called milestones can be distinguished. At each milestone the design team evaluates the product-design against the product requirements set at the start of the product-design process and chooses design alternatives. Ideally LCD should integrate environmental requirements from the beginning of this process in order to substantially improve the environmental performance of the product.

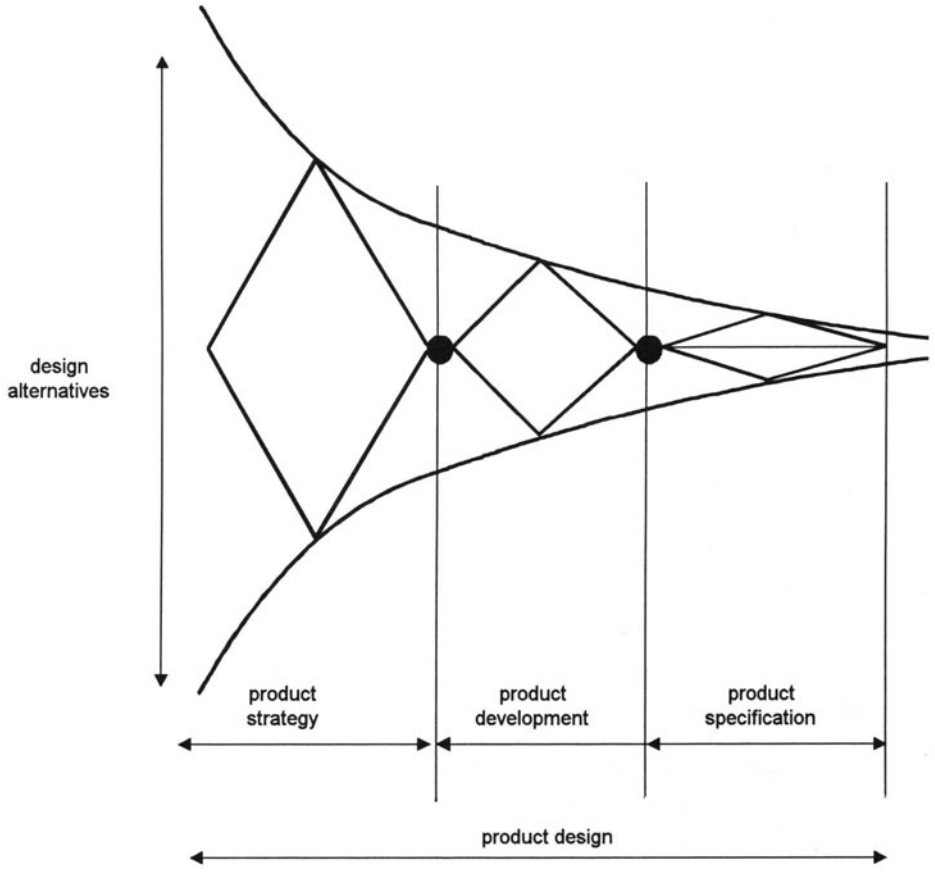


Fig. 5.2. An 'optimal' design process. (Kortman 1995)

Over the last few years tools have been developed which enable designers to analyze environmental impacts, identify improvement opportunities and evaluate the progress made in reducing environmental impacts. Based on practical experience, two types of tools have turned out to be of prime importance (van Berkel 1995):

- Assessment tools: enable LCD designers to identify the key characteristics that determine the environmental burden of a product throughout its entire life cycle. Furthermore, these tools enable designers to compare and rank different alternatives with regard to their environmental importance. Assessment tools
- Improvement tools: facilitate the generation of improvement options for products at different stages of the life cycle. Improvement tools

These tools can be roughly organized according to the three main stages of the design process, as illustrated in Table 5.1, with the corresponding tools for assessment and improvement.

Table 5.1. Overview of LCD tools

Types of Tools	Phase of Design Process		
	Product strategy	Product formulation	Product specification
Tools for assessment	1. Product-summary matrix	4. ABC scheme	6.Life cycle assessment (LCA)
Tools for generating improvement options	2. Brainstorming 3. Environmental principles	5. Checklist criteria	

This manual especially focuses on the tools for generating improvement options.

For the stage of product strategy, brainstorming (2) and environmental principles (3) can be applied to generate ideas for the environmental optimization of products. Environmental principles comprise relatively abstract environmental strategies.

For the stage of product formulation a combination of tools has been developed that consists of both the ABC prioritization method (4) and the checklist criteria (5). This tool is described in Chapter 6. Compared to the environmental principles, the checklist criteria comprise more detailed guidelines. They facilitate the generation of detailed improvement options for a specific product.

Additional assessment tools such as the product summary matrix (1) and LCA (6) are discussed in Chapter 8.

5.3.1 Product Strategy Stage

This section describes examples of tools for the stage of product strategy. In this initial phase of the design process, company management defines a strategy for product development for the years to come. This stage does not have to be linked to a specific product but it can be related to different product groups or use systems, which fulfil perceived customer needs. At this very early stage, potential environmental implications of choices concerning product needs can be addressed. For this purpose tools are required that help the design team develop general improvement ideas, and tools that provide a preliminary insight into the environmental burden caused by the realization of these ideas. The application of time-consuming tools for environmental assessment at this stage is disputable because a decision on the materialization of the ideas has not yet been made.

Therefore, other tools are required which can roughly indicate, in a

workshop or brainstorming session, the expected environmental problems as well as the benefits associated with an idea. Both the assessment and improvement tools for this stage are based on qualitative information. The Product-Summary Matrix was developed by AT&T for analyzing the possible environmental burden of a product. This tool consists of 5 x 5 matrix elements in which the various stages of the life cycle of a product are combined with environmental concerns. Each element can be filled in on the basis of a checklist. This tool is presented in Chapter 8. For the generation of innovative ideas, the following tools can be applied:

Brainstorming: In the field of LCD, brainstorming techniques can be employed at the beginning of a design process to collect ideas for environmental product innovation. By doing this collectively, associative thinking is encouraged. A brainstorming session should be well organized, the subject of the session should be clearly defined and the rules explained. The presentation of a few innovative examples of environmentally friendly products can stimulate the generation of ideas.

In the case of the VCR iR3 International GmbH, the starting point of the brainstorming session consisted of finding abstract definitions of the required functions formulated as: "the time-independent recording, storing, viewing and hearing of moving and standing pictures". The participants were encouraged to forget conventional ways of thinking and to freely identify environmentally sound alternatives without prejudice. In this case approximately 30 ideas were generated of which some could be implemented in the short run. The majority of ideas required cooperation with or strategic decisions by the company management.

Environmental Principles: Experience with brainstorming in the field of electronic products, such as lightening systems and video cassette recorders (VCRs), has shown how the participants can compare the results with a list of environmental principles. Such a list is used to verify whether the design team actually explored the entire range of LCD innovation strategies.

Several lists of design strategies and principles have been published in other publications. In this manual, thirteen environmental principles are presented:

P 1	Achieving environmental efficiency / optimal function
P 2	Saving resources
P 3	Use of renewable and sufficiently available resources
P 4	Increasing product durability
P 5	Design for product reuse
P 6	Design for material recycling
P 7	Design for disassembly
P 8	Minimizing harmful substances
P 9	Environmentally friendly production
P 10	Minimizing environmental impact of product in use
P 11	Using environmentally friendly packaging
P 12	Environmentally friendly disposal of nonrecyclable materials
P 13	Implementing environmentally friendly logistics

Although no specific selection can be made at this stage of product strategy, it is important to have criteria that are based on principles related to the whole product system and its surroundings. These criteria are described in Chap. 6. Examples are: design of green product systems (P 1), design of cascades (P 1), increase in product durability (P 4), design for product reuse (P 5) and the implementation of the concept of ecologistics (P 13).

„Hot-drink" machines

Example:
A project at Olland, a Dutch producer of 'hot-drink' vending machines, indicated that the manufacturing of the machine had a limited impact on the total environmental burden of its whole life cycle. Energy use and transportation associated with the use phase had major effects on its total environmental profile. In order to substantially improve the environmental profile of the product, a product-system approach was required, in a co-makership arrangement with the divisions of the company that operate upstream (te Riele 1994). A result of that was, for example, the optimization of the operation of the machine.

5.3.2 Product-Formulation Stage

In this section we describe some basic tools for the stage product formulation. In this phase the task is to design a specific product for a specific market, considering a set of requirements that have been formulated. The improvement opportunities are limited as environmental requirements must be balanced with other product requirements such as cost, performance, manufacturability, safety and styling. For this stage the following tools are available:

Checklist Criteria: More specific environmental design criteria are required to aid the designer. For specific environmental strategies, more detailed guidelines are already available, such as the German VDI's guideline 2243 design for recycling, which provides practical advice to designers. In this project, however, specific environmental design criteria have been further developed in connection with basic environmental principles. This was done on the basis of international experience and tests in eight case studies (see Chap. 6).

At this stage, attention should be focused on environmental criteria which define the framework for the chosen product-design. Examples are: reduction of material input (P 2), use of recycled materials (P 2), timeless design (P 4), design for dismantling (P 7). minimizing harmful substances (**P 8**) and saving energy in the use phase (P 10).

Example
On the basis of these principles, various ideas can be generated. In the case of Digital's recycling-oriented design of computer systems, three different recycling strategies for product use were selected on the basis of P 5 and P 7:
- Centralized automatic dismantling
- Batch-oriented dismantling, partly manual and partly automatical
- Manual batch-oriented dismantling

In this case different sets of requirements and designs were developed and analyzed for each strategy.

ABC Scheme: In this case, environmental design criteria are intended to be used for the systematic identification of improvement opportunities for a specific product or function. In order to enable designers to reveal weak spots, the ABC scheme can be applied in combination with the checklist criteria. In the ABC scheme, 'A' indicates that a criterion has been fully taken into account, 'B' shows a fair degree of implementation and 'C' an urgent need for environmental improvement. The combined tool which consists of both the checklist criteria and the ABC scheme is presented in Chapter 6.

5.3.3 Product-Specification Stage

At the product specification stage the design process is concerned with the practical preparation for manufacturing by formulating the details of parts and components. At this stage important investment decisions will be made. As a result, there is an urgent need for obtaining reliable environmental information upon which to base these decisions.

Experience has shown that the optimization of parts and components often involves environmental trade-offs (see Chap. 7). By emphasizing a

particular criterion for the environmental impact of a product, the environmental impact associated with another product criterion could increase. Therefore assessment tools are required that include prioritization elements to help determine if a certain option is really better than another. However, prioritization tools such as the life cycle assesment (LCA) are still in their infancy (see Chap. 8).

Towards the end of the design process, clearer environmental specifications are needed for the procurement of environmentally improved components and sub-assemblies. Such specifications, however, hardly exist. Some of the criteria presented in Chapter 6 can be applied at this stage, such as minimizing wear (P 4), enabling access to specific components for reuse (P 5), standardizing connecting elements (P 5), minimizing the variety of materials (P 6), marking of materials (P 6), designing for dismantling (P 7), allowing for easy removal of harmful substances (P 8), choosing production processes with minimal waste and emissions (P 9) and adding consumer information for the use phase (P 10).

6 Principles and Criteria

In order to make ecodesign operational it is necessary to establish guidelines and design criteria and to incorporate them into the development of new products and production procedures. Generally, the following environmental principles and criteria should be taken into account:

Guidelines and design principles

P 1	Achieving environmental efficiency / optimal function
P 2	Saving resources
P 3	Use of renewable and sufficiently available resources
P 4	Increasing product durability
P 5	Design for product reuse
P 6	Design for material recycling
P 7	Design for disassembly
P 8	Minimizing harmful substances
P 9	Environmentally friendly production
P 10	Minimizing environmental impact of product in use
P 11	Using environmentally friendly packaging
P 12	Environmentally friendly disposal of nonrecyclable materials
P 13	Implementing environmentally friendly logistics

Planners, designers and engineers are confronted with the question as to how to put these principles into action. To answer this question, a number of criteria have been formulated and examples will be presented that illustrate these principles. Thus the planner, designer and engineer are offered an overview of essential points in LCD, based on experience gained in life cycle design so far. There is, however, no single solution to the problem of producing an environmentally friendly product. The rules are intended to be used for a systematic evaluation in the development of environmentally sound products. In practice, the main objective will be the implementation of as many guidelines as possible, following demands such as those of functionality, quality, design and cost of the product.

Criteria

Examples

Summing up the criteria in checklists is of practical help. They are easy to integrate into the normal planning and design process. In every design step it is easy to check if all relevant criteria have been taken into account. Thus the designer will be confronted directly with all the important environmental aspects of LCD and will thereby be provided with suggestions on how to find better solutions.

Checklists

ABC scheme

The checklists are based upon a well-tested 'ABC scheme', which enables the user to quickly reveal weak spots: 'A' indicates that the criterion has fully been taken into account, 'B' shows a fair degree of implementation and 'C' indicates an urgent need for change and that new and better solutions should be generated.

6.1 Achieving Environmental Efficiency / Optimal Function

The criteria for the environmental principle of 'achieving environmental efficiency/optimal function' differ from those for the other 12 environmental principles because they reach beyond the environmental optimization of a single product and stimulate designers to formulate new ways of fulfilling customer needs. In doing so, the function and design of products as well as the boundaries of product systems are questioned. Applying this principle implies that an open evaluation of product-designs is made. This particularly makes sense in the phase of setting product strategy (see Chap. 5).

Function hierarchy

In order to illustrate this criterion, the concept of 'functional hierarchy' is introduced. An example of the functional hierarchy for 'food preservation' is presented in Fig. 6.1.

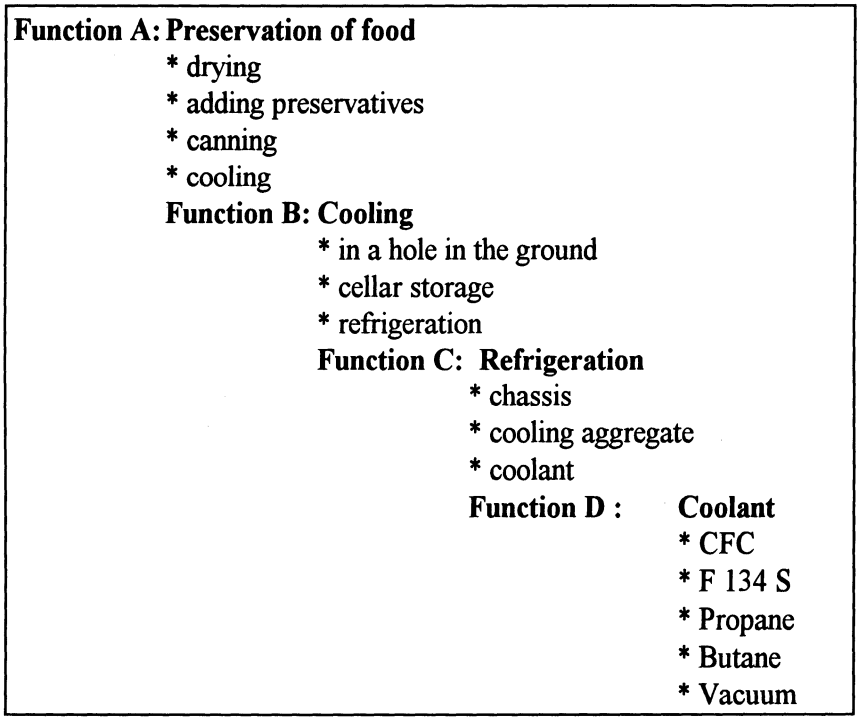


Fig. 6.1. Function hierarchy for the fulfilment of the need of 'food preservation'. (IÖW 1993)

In this hierarchy, four functional levels are distinguished. For each level alternative methods of fulfilment are given. Instead of focusing on the design aspects of a specific product (levels C and D), the criteria for an optimal function focus on levels A and B, where the scope of alternatives is relatively wide as are the opportunities for LCD.

There seem to be few incentives for industry to consider this functional hierarchy approach because it implies new ways of thinking, changes in the attitudes of designers and the behaviour of consumers, in combination with innovative technological shifts.

In practice these changes are already underway. New government regulations which give manufacturers responsibility for the environmental fate of their products favour the functional approach. The following four criteria can guide that approach in various directions (Fig. 6.3).

☝ The Needs and Demands of Consumers

The assessment and formulation or reformulation of the needs and demands of consumers question the design of products in the most fundamental way. In society there is an almost 'natural' tendency to encourage an increase in product use per person, in order to raise the level of individual material welfare. As a consequence, the level of environmental pollution increases as well. In order to reduce the environmental impact of both production and consumption, not only must technical aspects be taken into account but also values and behavioural aspects. The designer might ask whether consumer needs should be fulfilled in a 'greener' way by elimination, change or reformulation of products.

Although this strategy seems environmentally desirable, the practical implementation is difficult in the field of consumer goods. Firstly, the elimination of products does not normally fit in well with a company's general strategy according to which profits depend on sales. Secondly, the current willingness of consumers to take environmental action does not substantially reduce the diversity of the consumer goods they buy.

Examples of this 'greener way' are beginning to appear in other sectors such as energy and pesticides production and consumption. In the latter sector product use has declined dramatically, as farmers have adopted integrated pest management. In the sector consumer goods, emphasis should first be put on examples in which a 'greener way' of consumption can be combined with an acceptable and attractive life style for the majority of people.

Dematerialization

In order to reduce the material intensity of meeting needs, it may be possible to replace products by labour-based services that are tailored to the needs of customers.

Dematerialization can also be established by offering services in such a way that people can use products without having to individually possess them. Accordingly, leasing companies utilize products in a more effective way and products can be shared by various users. One example is the 'Call - a - Car' system in which the consumer has access to the use of a car whenever necessary.

Resource Cascading

Resource cascading is a method to extend the useful life of a resource by repeatedly utilizing it. In order to design for cascading, designers must apply the concept of 'consecutive relinking'. This means that they should keep the second (and following) applications of a material or product in mind while designing the first product. For example, in the cascade of paper (for packaging) certain additives and inks prohibit the reuse of the fibres in products of a higher quality.

The design of a cascade, in which various functions are considered, is not an easy task, taking into consideration that the design of a complex product itself is already very complicated. In addition, due to severe competition between companies, the economic life of electronic products has become very short as well as the period during which they are used (utilization time).

The challenge to designers is to determine what the most efficient resource route will be. This route can be planned by assessing the resource quality and by estimating the utilization time of the different secondary options (Fig. 6.2).

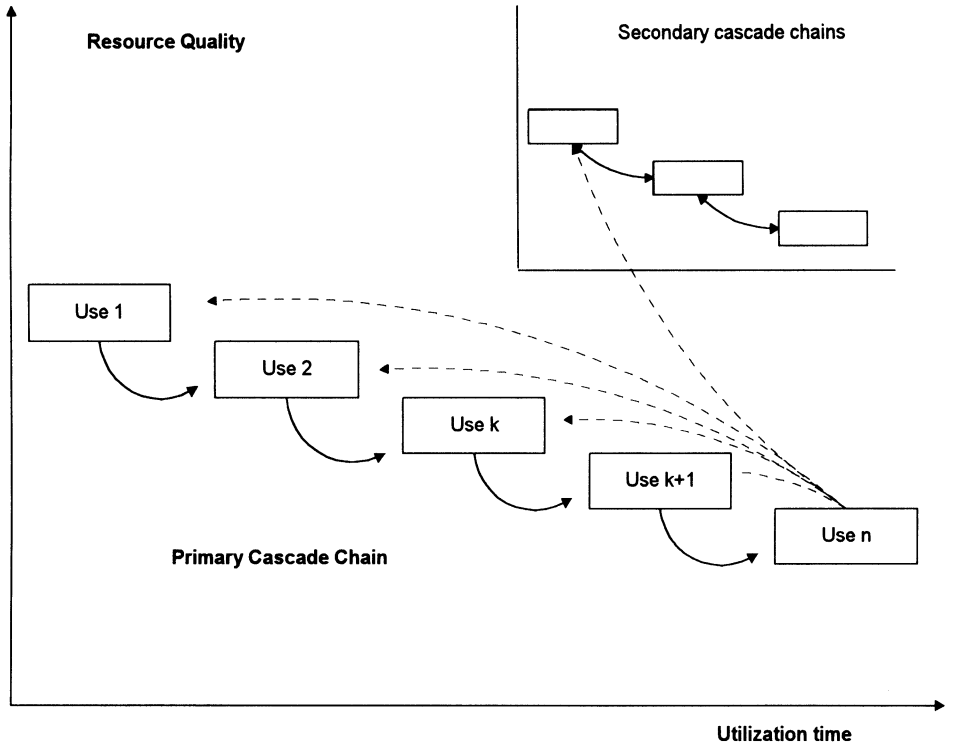


Fig. 6.2. A schematic presentation of different relinking opportunities

Design of Green-Product Systems

From an environmental point of view, products should be considered within the context of the product system in which they function. Whereas, on its own, a product may be classified as an environmentally unsound product, its performance in a product system may be considered an environmental benefit. An example would be the production of a workstation which requires hazardous chemicals but which at the same time increases the efficiency of manufacturing processes.

Therefore, life cycle design should ideally be linked to the 'design' of an entire product system, which consists of the product itself, together with other attributes that help the product fulfil its functions. This approach can lead to a combination of functions in one system of modules, for instance the integration of a TV set, a personal computer, a telephone and a fax machine. In this way, fewer products, attributes and materials can meet a greater variety of needs, while preventing a further extension of needs.

The environmental impacts of a product system can be reduced by means of initiatives that combine the selling of products with customer

services, such as information and assistance. An example is the policy of energy supply organizations, which are adopting new strategies. Whereas in the past they have been limited to the provision of energy, they are increasingly following more integrated strategies in which the provision of energy is combined with audit services and the promotion of energy-efficient equipment.

Checklist P 1

Criteria for environmental efficiency / optimal function	relevant for the product	Characteristics	Rating (Tick off Characteristics) A	B	C	No data available
Consumer Needs	☐	The company's strategy implies a reduction of consumer needs The needs of consumers are not influenced The product involved causes an extension of consumer needs	☐	☐	☐	☐
Dematerialization	☐	The product is substituted by a service Part of the product is replaced by service/usage by various consumers The product cannot be replaced by a service	☐	☐	☐	☐
Resource Cascading	☐	A cascade of more than two products is taken into consideration Two products are taken into consideration Attention is only paid to the first utilization	☐	☐	☐	☐
Product System	☐	The impact of the product system is considered and highly reduced (>50%) The impact of the product system is considered and reduced (0<i<30%) The impact of the product system is not considered / not reduced	☐	☐	☐	☐
Evaluation						
A = Ideal situation						
B = Acceptable situation						**LCD**
C = Urgent need for action						

Fig. 6.3. Checklist: Achieving environmental efficiency / optimal function

6.2 Saving Resources

The reduction of energy and material use in the production of a product leads directly to a saving of resources, to a lower environmental impact and to less waste at the end of the life span of the product. In addition, economic advantages can result from a reduced material input. The main potential for material input reduction is presented by the reuse of disassembled products and parts and by refurbishment for the spare part market or for other emerging markets.

It can be achieved on the basis of the following guidelines (Fig. 6.4):

Reduction of Material Input

Product or part size is a measure of the extent to which material input reduction has been achieved. A potential for a material savings can particularly be found in the design and selection of the casing of the model, which generally requires the largest amount of materials.

Flatbed-press

The flatbed-press 'High Print 4950' of the German company Siemens Nixdorf Informationssysteme GmbH is smaller than a normal press. Because of a special power management system, no extra ventilator is needed, thus reducing the volume that has to be enclosed in the product case.

Minimization of part size can be achieved by employing certain micro-technologies.

SMD-technology

Applying surface-mount technology in electronic products can also lead to size reduction. The surface-mount-devices (SMDs) used in this technology, such as capacitors or resistors, are usually much smaller than conventional electronic devices because casing and lead wires are no longer required with this type of construction.

Reuse Through Refurbishment ('Up-Cycling')

An efficient way to save materials is to refurbish a product for reuse. Today, only a very limited number of used products can be refurbished and reused. So the reuse of products will only gain importance if they are designed for that purpose from the beginning. In any case, opportunities for economic refurbishment should be taken wherever possible. For product evaluation, the following criteria are important (according to Brinkmann 1994):

Recyclability

Technological criteria (kind and amount of parts, variety of materials, complexity of design structure):

- A simply structured product made of a single material, such as a hydraulic pump with a grey iron casing, is suitable for material recycling. More complex products with a greater variety of materials (e.g. photocopying machines) are more suitable for refurbishment.

Amount criteria (amount of units produced, spatial and time distribution; demand for refurbished products):

- A product with a low value is only suitable for refurbishment if a large number of units is available in a limited collection area, as with tyres or telephones.
- Having a large collection area and a low number of available units a product would only be suitable for refurbishment from a certain value upwards.
- A product with an average number of units and a medium value is more often than not unsuitable for refurbishment. Here, pre-conditions for reuse should be created or preference given to material recycling.

Value criteria (material value, production value, assembly value):

- A product with a high production value would be more suitable for refurbishment. Recycling of the materials involved is more economic for products with a high material value. If the product has a high assembly value, refurbishment is the appropriate alternative.

Time criteria (product usage time, moment of refurbishment):

- In general, the longer a product can be used technically and economically the more suitable it is for refurbishment. Likewise, this applies to products with a short innovation cycle such as computers. Here, the usage time can be limited to only a few years because of the fast development of new technologies. Refurbishment has economic advantages compared to the complete production of a new product. Therefore, 'up-cycling' would be preferable to recycling.

Disposal criteria (amount of hazardous substances):

- The amount of hazardous substances in a scrapped product can impair or even block refurbishment, especially if the hazardous materials are difficult to remove.

Currently, there are some examples of economic refurbishment and re-marketing:

Hewlett-Packard

Hewlett Packard, for instance, takes back old devices for refurbishment and offers the refurbished equipment for sale. For certain parts which can no longer be reused in Hewlett-Packard equipment, new markets on a lower technology level have been discovered (e.g. in the toy industry).

Drink machines

In the United States, some medium-sized companies offer refurbishment

of drink machines. The refurbishment not only includes a new front design but also technological updating of the interior parts. Instead of the electromechanically controlled old devices with no money-return function, the refurbished machines are equipped with an electronic coin-changer. From an economic point of view, refurbishment is worthwhile, as such a machine can be obtained at half the price of a new one.

If refurbishment of the whole product is out of the question, then the use of refurbished product parts in the production of new products is a good option.

Engines

Nowadays there are a number of areas in which refurbished parts are used. In the case of automobiles, parts such as engines, gear boxes, starters, dynamos, propeller shafts, hydraulic pumps and break cyclinders lend themselves to refurbishment. In the electromechanical industry, tools such as drills, angle grinders and circular sawing machines undergo refurbishment as well as household appliances such as vacuum cleaners and hot-water boilers. Furthermore, parts of franking machines, photocopiers and personal computers, including their peripheral components, are 'up-cycled'. In the mechanical engineering industry, certain parts of machine tools, industrial robots, vending machines and chain saws are also reused after refurbishment.

As a rule, the quality of the refurbished parts is comparable to that of new parts; in some cases the quality is even higher. Especially engines are classic exchange parts for use in new products. Also, electronic devices such as memory chips and processors have a long durability and are therefore suitable for reuse. Therefore, an economically attractive market for high-quality electronic components has been established, mainly by middle-sized companies. But also big computer manufacturers have discovered remarketing: Hewlett Packard in Grenoble (France), IBM in Rodgau (Germany), DEC in Nijmegen (The Netherlands) and Siemens-Nixdorf in Paderborn (Germany).

So 'up-cycling' is not only a technical vision for the future. It has already been put into practice today, as more examples show:

– Deutz Service produces recycled engines with refurbished cylinder heads which have a stronger surface because of a special high-pressure wet cleaning process, making them more resistant to cracks.	Engines
– Siemens Nixdorf Informationssystems GmbH refurbishes electronic tills.	Tills
– Rank Xerox refurbishes parts of used photocopy machines to the extent of 51% of the weight of the collected machines for reuse in 'green-line' photocopiers.	Copiers
– Pelikan takes back used toner-modules for refurbishment. After cleaning, exchange of worn parts and a technical check-up, the modules are refilled again.	Toner
– Bosch Elektrowerkzeuge GmbH refurbishes electric engines from used drilling machines and puts them into new products.	

Use of Recycled Materials

Recycling only makes sense from an environmental point of view if a market exists and companies are willing to use recycled materials in their products.

Recycled materials can usually be substituted for new ones without any problems. Their quality is only slightly lower than that of comparable new materials. Often they are available at lower prices. This is especially true of most metals. The use of recycled plastics in new products, however, is not easy. The recycled plastics that are offered on the market are not always suitable for high-quality applications because of the hazardous substances and impurities they might contain or because of their colour. It is therefore important that the use of recycled plastics be taken into consideration in every design phase, especially when there is no specific demand with respect to material quality or colour.

The examples given below illustrate the range of high-quality applications for recycled plastics: Examples

Vacuum cleaner	– The casing base of the vacuum cleaner 'Öko-Vampyr' from AEG is made of high-quality recycled plastic. All together, 37.4% of the plastic parts are made from recycled plastics. The recycled materials originate from scrapped plastic car parts and plastic production waste, which is regranulated while adding antistatics and colouring substances. Here, thermoplastics, such as ABS (Acrylonitrite-Butadiene-Styrene) for the suction tube or an ABS/PS blend for the base, are used.
Washing machines	– AEG uses recycled plastics for the casing of washing powder compartments in washing machines. Ventilation parts in the base of dryers contain a material made from plastics that are derived from used car batteries.
Lawn mower	– Wolf-Geräte developed a lawnmower of which, for the first time, the entire chassis was made of recycled materials. All ABS plastic parts of the mower consist of parts from old mowers which have been returned and presorted by the dealers. The parts are washed, shredded, melted and compounded, with only few materials added, then regranulated and extruded into new components. The ABS regranulate fulfils all requirements with regard to resistance to weather conditions, security and durability. Potential weak spots were balanced out by a slightly higher material density.
Computer	– The housing of the eco-PC from Siemens Nixdorf Informationssysteme GmbH is made from recycled materials.
TV set	– Grundig produces a granulate which is made from the production waste and plastics from returned TV sets and is used to produce new injection-moulding parts for new sets.

Checklist P 2

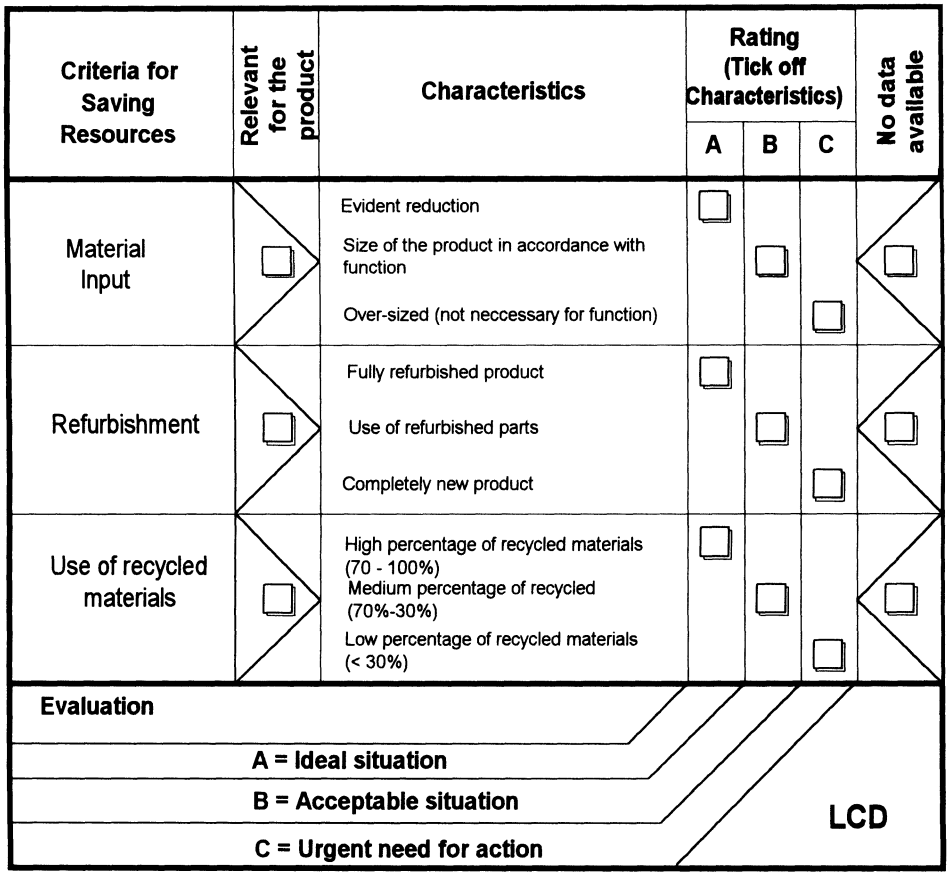


Fig. 6.4. Checklist: Saving resources

6.3 Use of Renewable and Sufficiently Available Resources

Up to now, the use of renewable resources, such as materials based on crops, compost and animals for complex products has been considered rather unconventional. This can be related to the characteristics, availability and relatively low costs of nonrenewable resources. It would be unwise to assume that there will be an infinite abundance of nonrenewable resources in the future. Given the growing world population, reductions in the use of metals such as copper, tin and silver will be necessary before the year 2050 (Legarth 1995). According to the Wuppertal-Institut a reduction of the use in nonrenewable resources by about 80 - 90 % will be necessary in the long run.

Advantage of renewable resources

In comparison with nonrenewable resources, renewable resources show advantages: they will not be depleted if managed properly, the use of these materials is neutral with regard to CO_2 emissions and after disposal they are biodegradable. These are good reasons for raising awareness of the potential uses of renewable resources. The following criteria have been developed to draw attention to the opportunities for selectively reducing the use of nonrenewable, scarce resources (Fig. 6.5).

Replacing Nonrenewable Resources with Renewable Resources

In the last few decades, industry in general has shifted towards the use of materials based on metal ores and fossil fuels. Currently, well-known examples of renewable resource usage are found other than in complex products: for example in furniture and building elements. In practice other interesting options for application exist, such as fibres, starches, biochemicals and bioplastics (Tromp 1995).

In order to assess the possibilities of substitution, a comparison of the characteristics of renewable and nonrenewable resources is essential. In doing so, the characteristics of different types of renewable resources such as trees and shrubs, agricultural crops, roots and tubers, animal tissue and organic waste materials must be identified. In the case of electricity cables, plastics for the insulation and filling layers can be replaced by materials from agricultural crops such as jute and hemp.

Transformation technologies are applied to improve the quality of materials from renewable resources. Replacing scarce tropical wood with soft European wood, for example, is difficult because of the better quality of tropical wood, which usually contains more lignin and therefore has harder cell walls. In order to overcome this difficulty, softwood is often treated with paints or preservatives. To eliminate the

use of these harmful substances, new techniques have been developed. The so-called 'Plato' process is an example of a new technique that can be used to protect softwood without adding chemicals. The Plato process changes the structure of soft wood by high pressure and high temperature. In this way a new kind of material is created with properties similar to those of hardwood.

Packaging

Another idea is that especially nondurable products (such as packaging for complex products) should be based on renewable resources. The German law obliges companies to take back packaging, except for that which can be composted. In order to design compostable packaging, a good understanding of the process requirements of the materials (the organic fraction) and the composting process is needed. Organically-based packaging materials, such as straw, wood, other cellulose-based materials and modern compostable materials such as polybutyrate or starch, may be suitable for composting. These materials, however, are often coated or laminated with polyethylene, wax, spray, coatings or prints. It is important to determine whether or not these coatings or laminates limit microbial access or if they contaminate the final compost.

Replacing Scarce Materials with Less Scarce Materials

Estimating the scarcity of a material resource is a complex task. Although the quantities of many minerals in the earth's crust seem to be very large, various minerals have such a low concentration that the actual resource potential is very low. In Table 6.1, a list of the production weight and the resource potential of nine minerals is presented.

Table 6.1: World production and reserves in 1977 (Barney 1981)

	Production (10^6 t)	Resource potential (10^6 t)
Aluminium	17	3519000
Antimony	-	19
Chromium	3	3260
Copper	8	2120
Iron	495	2035000
Mercury	0.008	3.4
Platinum	0.0002	1.2
Silver	0.01	2.8

Complex products

In complex products, various relatively scarce materials are used, such as antimony, chromium, gold, platinum and silver. The use of these scarce materials can be decreased by substitution. An example is the replacement of copper with aluminium in cables in the electronic industry. In the case of substituting nonrenewable resources, attention should be given to the new risk that this substitution may shift the high consumption rates of currently scarce resources to resources that will become scarce themselves as a result. Substitution should therefore be combined with a reduction of use, optimization of recycling and the maintenance of an adequate stock.

The replacement of renewable resources depends on factors such as the extraction rate and human influence (land-use requirements). Renewable resources that are exploited much faster than they can be replaced should also be considered as scarce resources. An example is the rapid depletion and degradation of tropical forests.

In order to guide designers in selecting materials with sufficient supplies, depletion factors for resources have been developed. The quantity of primary resources can be measured relative to the availability and quality of resources (Heijungs 1992).

Minimizing the Use of Scarce Materials

The last strategy to minimize the depletion of scarce resources is a reduction in the use of scarce raw materials by miniaturization, recycling and extended product life. Due to miniaturization the content of a standard colour TV set has already been decreased from 1500 g of copper in 1975 to about 800 g in 1990. Raising the recycling rate of rare materials in complex products will further decrease the total use of these materials (see principle 5).

Checklist P 3

Criteria for the use of renewable sufficiently available resources	relevant for the product	Characteristics	Rating (Tick off Characteristics) A	B	C	No data available
Use of renewable Resources	☐	All reasonable alternatives from renewable resources are applied Some nonrenewable resources are replaced by renewable No attention has been given to this criterion	☐	☐	☐	☐
Use of less scarce materials	☐	No virgin scarce materials are being used Reasonable alternatives for scarce materials are applied No attention has been given to this criterion	☐	☐	☐	☐
Minimization of the use of scarce materials	☐	The use of scarce materials is reduced by more than 20% The use of scarce materials is reduced by less than 20% Not reduced	☐	☐	☐	☐
Evaluation **A = Ideal situation** **B = Acceptable situation** **C = Urgent need for action**						**LCD**

Fig. 6.5. Checklist: Use of renewable and sufficiently available resources

6.4 Increasing Product Durability

As a prevention strategy, increasing the durability of a product is of particular importance. It directly prevents some of the burden upon the environment, it reduces the use of resources and it minimizes waste. Doubling the lifetime of a product would result in half the amount of waste. Generally, an increase in product durability slows down the material flow during the entire life cycle.

This can be achieved mainly by devising products with a long life span, by using a product-system design that is technologically adaptable and by designing for maintenance.

Products designed for durability

The durability of products depends mainly on their reliability, the wear of their materials or components, and their timeless and trend-surviving design (Fig. 6.6).

Optimizing Reliability

The products or their components, must be designed against wear (mechanical, thermal etc.) in an optimal way. This also applies to environmental influences (dust, humidity, heat, vibration etc.). The product should therefore be designed in such a way that external influences cannot affect its reliability. Damage in electric and electronic devices caused by overheating should be restricted to the respective component. Therefore, fire-safety measures are necessary. The use of flame retardants that are harmful to health or the environment should, however, be eliminated.

Minimizing Wear

Wear that is not caused by function should, if possible, be eliminated or at least minimized. Only those parts or components should be subject to wear and tear that have been so designed. It should be easy to exchange and process them. Components that are particularly prone to wear such as cable holders on vacuum cleaners can also be made stronger in order to last longer. Furthermore, the product or part should be designed in such a way that it will not be exposed to corrosion or, at least, protected against it.

Timeless Design

The design of the product should be as timeless as possible so that its technical potential will be fully exploited and it will not be prematurely

scrapped because of a change in trends. A design independent of trends also facilitates the 'up-cycling' of older appliances by technical upgrading. The casings of the appliances could, in this case, remain intact.

Adaptable system design

The constant development of technologies causes products to become obsolete much faster than they would through normal use. Product-design should therefore take adaptability to future technological developments into account. This is particularly applicable to products with short innovation cycles such as computers, laser printers and fax machines. Otherwise these products become waste after only a short period of use.

Realising the Use of Modules

Modular structures, for example, facilitate later adaptation to technological developments.

Taking into Account Future Technological Developments

Mobile telephones and TVs

Foreseeable technological changes should already be taken into account in the early stages of product development. Examples are mobile telephones, which were manufactured as C-network devices but are now adaptable to the D1 and D2 networks which were introduced at a later stage. Another example are colour TVs which were conventionally designed for receiving signals by air but were equipped with an additional cable tuner once the trend towards cable TV became obvious.

Construction for maintenance

Product durability can be increased if the products in question and their components can be cleaned, serviced and repaired without problem.

Easy to Clean

Products and their reusable components should be designed in such a way as to facilitate cleaning. Therefore, smooth and robust surfaces should be chosen and small crevices, dead corners and inaccessible inner spaces avoided.

Easy to Maintain

Maintenance requires easy access to components and their easy exchange. This can be supported by electronic self-diagnosis functions. Maintenance is primarily worthwhile for investment goods such as machines or appliances on lease, e.g. copiers or laser printers.

Easy to Repair

In the case of damage or loss of function, the servicing of the products should be fast and easy. This primarily applies to products of average or high value, as from a cost point of view repairs are only worthwhile up to a certain minimum value.

In order to be service-friendly, it should be easy to take an appliance apart. Parts that are worn should be easily accessible. In the example of a vacuum cleaner this would apply to the hose connection, the cable drum, rollers and coal brushes.

Long Warranty Period

Long warranty periods support the service-worthiness of products upon malfunctioning or damage. Therefore, they should be extended: for complex household goods the average warranty period is 6 to 12 months; however, 5 years is quite feasible.

Checklist P 4

Criteria for Increasing Product Durability	relevant for the product	Characteristics	Rating (Tick off Characteristics) A	B	C	No data available
Reliability	☐	Above average	☐			☐
		Average		☐		
		Below average			☐	
Wear	☐	Low (with normal use), restricted to easily exchangeable components	☐			☐
		Medium wear, affected components exchangeable		☐		
		High wear without exchangeability of components			☐	
Timeless design	☐	Timeless design	☐			☐
		Contemporary design		☐		
		Fashionable short-lived design			☐	
Use of modules	☐	Modular structure	☐			☐
		Partly modular structure		☐		
		Complex structure			☐	
Future technical developments	☐	System design adaptable to future developments	☐			☐
		System adaption possible		☐		
		No system adaptation possible			☐	
Easy cleaning	☐	Cleaning easily possible	☐			☐
		Acceptable expenditure for cleaning		☐		
		Cleaning not possible			☐	
Maintenance-friendly	☐	Maintenance-free	☐			☐
		Low expenditure for maintenance		☐		
		High expenditure for maintenance			☐	
Repair-friendly	☐	Easy to repair	☐			☐
		Acceptable expenditure for repair		☐		
		Repair not possible			☐	
Guarantee period	☐	> 5 years	☐			☐
		< 5 years		☐		
		< 1 year			☐	

Evaluation

A = Ideal situation

B = Acceptable situation

C = Urgent need for action

LCD

Fig. 6.6. Checklist: Increasing product durability

6.5 Design for Product Reuse

Reusable products can be introduced into further usage cycles. Thus, material flows will be slowed down, fewer resources will be required and more emissions prevented.

A precondition is that refurbishing and reconditioning are considered in the design of the product. For some products, such as engines, the quality and value of the reconditioned engine can be higher than that of the new product.

Rules

Reusability is also supported by maintenance-friendly design. A timeless design also promotes the reuse of a product. In detail, the following rules should be taken into account (Fig. 6.7, p. 76):

Modular Design

The components of a product should be arranged in a modular structure in order to allow simple exchange or easy refurbishment.

Easy Access to Components

In order to facilitate the refurbishment of a product, all its components should be easily accessible. Here the criteria of design for easy disassembly apply.

Reduction of Wear to Individual Components

Wear should be limited to a few, easily exchangeable or reusable components, e.g. switches, coal brushes and brake pads.

Protection Against Corrosion

The products are to be designed in such a way that corrosion cannot develop or that there is sufficient protection against it. This means that:

- There should be no crevices and dead-ends in components prone to corrosion or these spaces should be sealed.
- Sharp edges and rough surfaces etc. should be avoided.
- Casting, forging or rolling skins should remain undamaged.
- Water collection or condensation should be avoided.
- Screw connections can be unscrewed at any time to facilitate damage-free disassembly for reuse.

Standardization of Components and Connecting Elements

Components and connecting elements should be standardized. Therefore, in product planning, the national and international standardization efforts (DIN, ISO etc.) should be taken into account. Internal standardization should support these efforts. It not only facilitates the later reuse of products and components but, in addition, allows considerable ease of production, maintenance and disassembly.

Checklist P 5

Criteria for product reuse	relevant for the product	Characteristics	Rating (Tick off Characteristics) A	B	C	No data available
Modular design	☐	Modular structure	☐			☐
		Partial modular structure		☐		
		Complex structure			☐	
Components accessibility	☐	Components easily accessible	☐			☐
		With acceptable expenditure		☐		
		Components inaccessible			☐	
Wear	☐	Little to no wear	☐			☐
		Restricted to individual components		☐		
		High wear, no reuse possible			☐	
Protection against corrosion	☐	Materials resistent to corrosion	☐			☐
		Protection against corrosion		☐		
		No protection against corrosion			☐	
Components standardization	☐	All components standardized for reuse	☐			☐
		Individual components standardized		☐		
		Little to no standardization			☐	

Evaluation

A = Ideal situation

B = Acceptable situation

C = Urgent need for action

LCD

Fig. 6.7. Checklist: Design for product reuse

6.6 Design for Material Recycling

Scrapped products constitute a valuable source of raw materials which can be reused as materials of the same quality or, otherwise, as materials with modified characteristics. Rather than using primary materials, the goal should be to use secondary materials without loss of quality. This means that disassembly of recyclable components must be feasible. In addition, the product should consist of recycled materials that are suitable for the relevant processing technology and for the quality required (see design for disassembly). Recycling-friendly design therefore involves a concept that, in particular, indicates what recycling methods can be used. Therefore, design features must be chosen accordingly.

'Green television'

For example, the 'green television set' by Loewe Opta GmbH is based on a recycling concept under which the whole TV set is made from a single material and can be reused as scrap steel, except for the tube. The appliance, including the electronics, is designed in such a way that it meets all the requirements for high-quality steel recycling (see Chap. 10 Environmentally innovative cases).

Rules

A recycling-friendly design is promoted when the following rules are applied (Fig. 6.12):

Use of Recyclable Materials

In principle, reusable materials should be applied. They are to be sorted according to type of material. Polystyrene, for example, is a substance that is very suitable for recycling. However, as a blend (such as Noryl) its recycling value will already be reduced drastically. In recycling this polymer, old material contributes only 20% of the weight. The remaining 80% must added in the form of primary raw material.

Because of the recycling obstacles they pose, the amount of laminated materials should be reduced to a minimum. They should be limited to applications for which there are no technically feasible alternatives.

Aiming for a Minimal Variety of Materials

Aiming for as little variety as possible means that products and components could be more easily recycled. Ideally, a product should consist of only one material and, upon recycling, should allow a high level of reuse. With complex products, different materials are generally used because of the high and varied requirements. Serious consideration should be given, however, to the minimization of material variety.

This applies especially to composite structures and to plastics, where the separation into clean components as a precondition for high-quality recycling still presents a processing problem. In order to reduce material variety, components that have the same function, such as casing parts, should be made from uniform materials.

Fig. 6.8 illustrates the relationship between single-material and multiple-material systems with respect to recycling aspects and the integration of different functions in individual components.

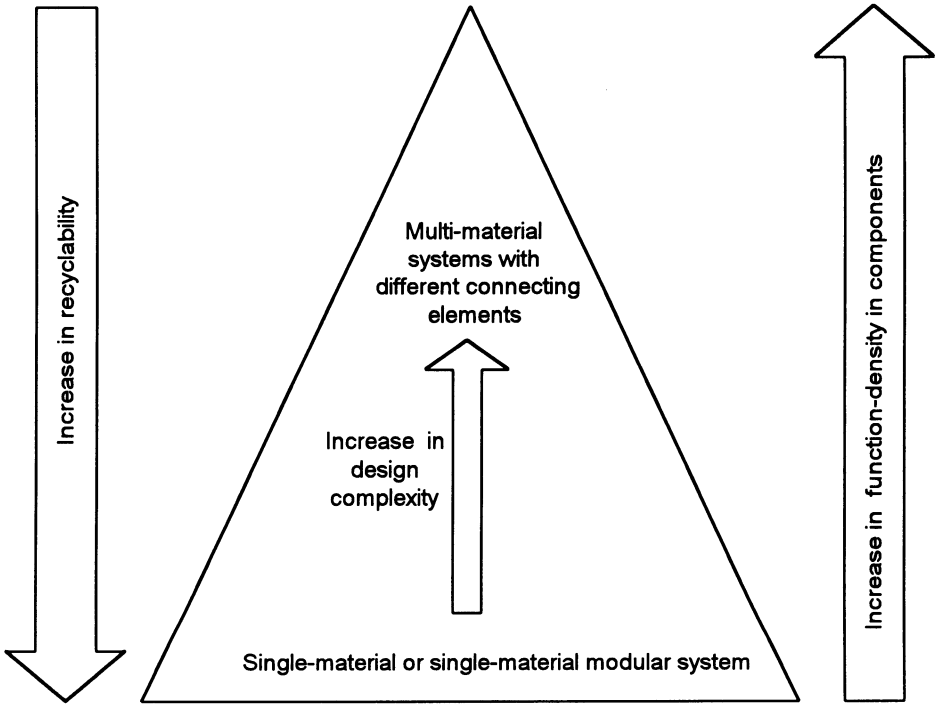

Increase in recyclability
Multi-material systems with different connecting elements
Increase in design complexity
Single-material or single-material modular system
Increase in function-density in components

Fig. 6.8. Increase in recyclability in relation to material variety. (According to Herren)

Index

Based on the ideal of a single-material product, an index has been developed which takes into account material variety as well as the weight distribution of the different plastics related to the number of components. The closer the index is to 1 - corresponding to a single-material product - the more effective it is to recycle the plastics.

$$\text{Index} = \sum \frac{\text{Number of components}_{\text{Fraction}}}{\text{Number of components}_{\text{Total}}} \cdot \frac{Weight_{Fraction}}{Weight_{Total}}$$

A newly developed coffee maker produced by Bosch-Siemens Hausgeräte, Munich, shows that it is possible to keep material variety at a minimum. The plastic portion consists of polypropylene only, which, with 56.6% of the total weight, represents the largest share. By a simple blow of a hammer, the plastic components can be separated from the other components such as glass, metal, lead and silicone. Thus, upon material sorting, 98% of the weight can be recycled.

Coffee maker

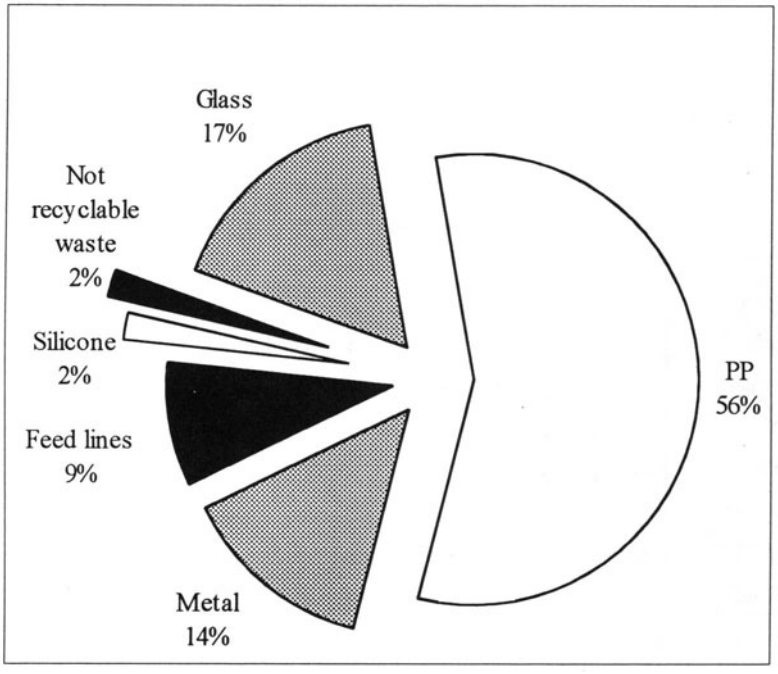


Fig. 6.9. Material composition of a recyclable coffee maker manufactured by Bosch-Siemens Hausgeräte GmbH

Material Compatibility Guaranteed

Most materials, especially different plastics, cannot be combined in material recycling because of their different chemical and physical properties. Even the smallest addition of an incompatible material often leads to a considerable deterioration of the physical and constructive characteristics of the recycled material, which allows reuse only at a low quality level.

If a product must be constructed from several materials, it is important to make sure that the material combinations chosen are compatible

upon recycling. Assembly units in particular should be made of compatible material groups in order to accelerate disassembly for recycling and to render it economically worthwhile.

Information about materials that are acceptable to the recycling process can be obtained from recycling companies in the form of material-combination compatibility lists.

Plastics

For plastics, the following combinations should be adhered to:

Matrix material: Important construction materials	Additional material: PE	PVC	PS	PC	PP	PA	POM	SAN	ABS	PBTP	PETP	PMMA
PE	■	⊗	⊗	⊗	■	⊗	⊗	⊗	⊗	⊗	⊗	⊗
PVC	⊗	■	⊗	⊗	⊗	⊗	⊗	■	◘	⊗	⊗	■
PS	⊗	⊗	■	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
PC	⊗	*	⊗	■	⊗	⊗	⊗	■	■	■	■	■
PP	*	⊗	⊗	⊗	■	⊗	⊗	⊗	⊗	⊗	⊗	⊗
PA	⊗	⊗	*	⊗	⊗	■	⊗	⊗	⊗	*	*	⊗
POM	⊗	⊗	⊗	⊗	⊗	⊗	■	⊗	⊗	*	⊗	⊗
SAN	⊗	■	⊗	■	⊗	⊗	⊗	■	■	⊗	⊗	■
ABS	⊗	◘	⊗	■	⊗	⊗	*	⊗	■	*	*	■
PBTP	⊗	⊗	⊗	■	⊗	*	⊗	⊗	*	■	⊗	⊗
PETP	⊗	⊗	*	■	⊗	*	⊗	⊗	*	⊗	■	⊗
PMMA	⊗	■	*	■	⊗	⊗	*	■	■	⊗	⊗	■

■ compatible
◘ limited compatibility
* compatible in small quantities
⊗ incompatible

Fig. 6.10. Material compatibility of plastics in recycling. (VDI 1993)

Steel

With metals such as steel, even small impurities of other metals such as copper or zinc, can cause a tendency to fracture because of brittleness and limited elasticity.

Aluminium

This also applies, to some extent, to aluminium alloys. Especially malleable alloys (metal sheets, profiles) as used for casings must not be mixed with so-called casting alloys for pressure casting moulds. This requires total disassembly of the appliances before material recycling, which can render the recycling process uneconomical. It is therefore

important, in the design stage, to get as close as possible to a single-material product. It may sometimes even be sensible, from a recycling point of view, to use materials which seem 'overqualified' for the intended use in the appliance in order to obtain a standardization and simplification of the material range and to fulfil the requirements for a closed-material cycle.

Use of Additional Materials According to Recycling Requirements

Protection against corrosion, paints, flame retardants, plastic coatings, surface treatments, antistatics, stabilizers, softeners, biocides etc. all impair recycling. Additional materials sometimes make up half the original material weight of a product. More often than not it concerns rather problematic materials, which in reprocessing accumulate in the recycled material thus turning it into a collection of harmful substances. In this case recycling can become a questionable process. Examples are plastics which contain cadmium or lead or flame-retarding agents.

Examples

Additives can render originally clean materials unacceptably impure for the recycling process. In the case of PVC, recycling leads to the spreading of cadmium even to cadmium-free application ranges. Additives should therefore always be chosen with regard to their suitability for recycling (as well as their hazardous potential).

Printing paint

Large spray (paint) surfaces on plastic parts require extra processes for removal if the plastics are to be recycled. They can hinder the identification of different plastics. Therefore it is better to avoid their usage. Printing, pigmentation or elements for decoration (such as metal mica) can also cause impurities and thus prevent high-quality recycling. Their usage should be kept to a minimum.

Planning of Material Marking

In order to guarantee problem-free sorting and recycling of materials, it is necessary to be able to identify materials and packaging without time-consuming checking methods. Clear marking would allow quick separation of materials.

With plastics, it is of special importance to keep them separated according to material type in order to obtain secondary raw materials with acceptable, well-defined characteristics. Therefore, in general, plastics should be marked.

There are already two different types of standardization for plastic components according to DIN 54840 or ISO 11469 and DIN 6120 for packaging. These standards should always be followed with respect to

marking. The mark contains a recycling symbol under which the real identification is indicated - for plastics, the abbreviations for the polymers are given, which have been standardized. If the plastic consists of several basic materials, then the abbreviations are linked by a plus sign. In case flame retardants have been used, then the addition 'FR' should be indicated according to DIN 54840. For filling or strengthening materials, an abbreviation that indicates the percentage should be added. Moreover, any material that could present a problem for reprocessing, reuse or waste disposal should be marked as well (for example, cooling agents in cooling aggregates, cooling oil in transformers).

In general, marks that allow a quick and unambiguous identification should be chosen. At present, there are three basic kinds of identification:

- Marking through machine tools.
- Marking through print or embossing, especially with packaging foils.
- Marking with bar codes that can quickly be checked with optical reading devices.

So far, mainly the first two processes have been applied. However, the application of bar codes, as well as infrared and X-ray fluorescent spectroscopy has increased because of their high accuracy and time efficiency: it takes only three seconds to identify the plastics.

Videotape

BASF, a German company, has developed a coding system for the identification of internal video tapes which facilitates the automatic separation of different materials. The code can be read by an optical registration device.

Within the framework of the EUREKA project 'Care Vision 2000', several European enterprises are attempting to find technical solutions for storing information on manufacturing and usage data ('green data') in so-called identification units on the products. Via interface, a 'green port', these data can later be accessed by recycling companies to retrieve detailed information with regard to feeding stock for disassembly, components containing harmful substances and possibilities for reuse and refurbishment.

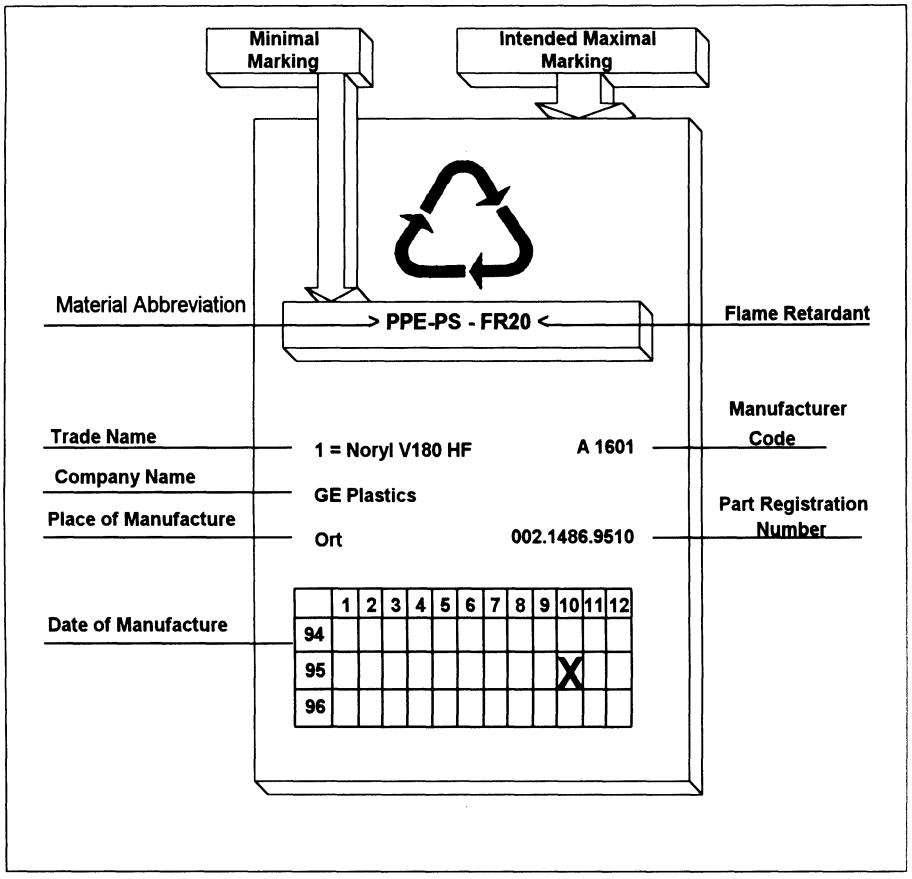


Fig. 6.11. Marking of material

Checklist P 6

Criteria for material recycling	relevant for the product	Characteristics	Rating (Tick off Characteristics) A	B	C	No data available
Recyclability	☐	Materials suitable for high-quality recycling	☐			☐
		Recyled material suitable for other application areas		☐		
		Materials poorly suited or unsuitable for recycling (compounds)			☐	
Use of recyclable materials	☐	High percentage of recyclable materials	☐			☐
		Medium percentage of recyclable materials		☐		
		Low percentage of recyclable materials			☐	
Material variety	☐	Close to a single-material product	☐			☐
		Low due to function		☐		
		High although not due to function			☐	
Material compatibility	☐	One-material product	☐			☐
		Compatible in recycling		☐		
		Incompatible in recycling			☐	
Additional materials	☐	Additives compatible in recycling; non-toxic	☐			☐
		Easily separable; non-toxic		☐		
		Incompatible in recycling; hazardous to health and environment			☐	
Marking of materials	☐	Machine-readable	☐			☐
		According to DIN or ISO		☐		
		No marking			☐	

Evaluation

A = Ideal situation

B = Acceptable situation

C = Urgent need for action

LCD

Fig. 6.12. Checklist: Design for material recycling

6.7 Design for Disassembly

Disassembly of a product should be easy to achieve without damage. Quick and damage-free disassembly is a precondition for obtaining reusable components and reusable materials sorted according to material groups. Therefore, from an environmental point of view, design for easy disassembly should be a goal. It is also essential for a controlled extraction of harmful substances, and should be made feasible for detaching or destroying connecting elements. This can be done, for instance, by means of predetermined breaking points. The most disassembly-friendly products are, without doubt, those that have only few connecting elements.

Rules

The ease of disassembly of a product depends on the following rules (Fig. 6.14, p. 88):

Structure Geared to Disassembly

Sandwich structure

Especially easy to disassemble are structures that are based on a hierarchical principle, having a central component and a tree structure, with individual components arranged from trunk to branches. Sandwich structures are also easy to disassemble. They allow a very efficient disassembly process because all components can, one after the other, be reomoved from the central component. The following illustration shows an example of such a structure (Fig. 6.13).

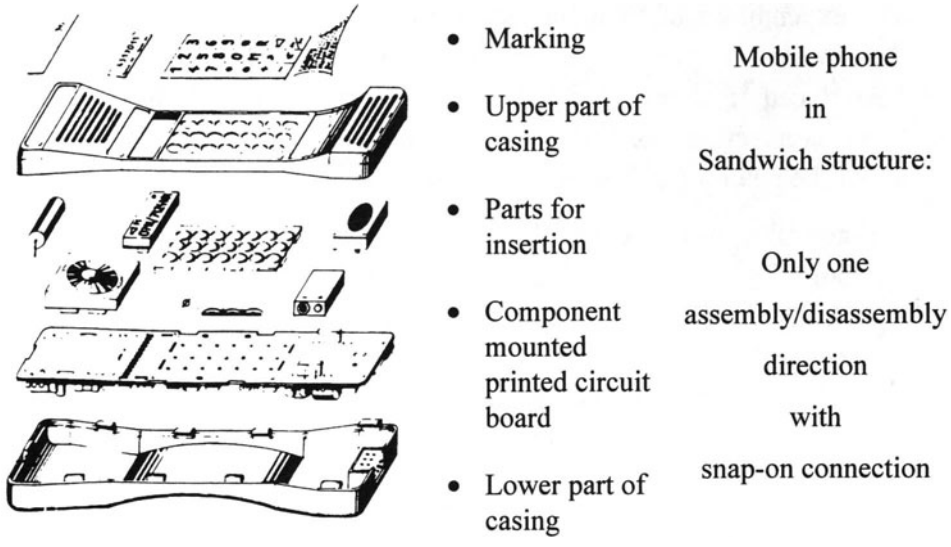

• Marking
• Upper part of casing
• Parts for insertion
• Component mounted printed circuit board
• Lower part of casing
Mobile phone in Sandwich structure:
Only one assembly/disassembly direction with snap-on connection

Fig. 6.13. Telephone in a sandwich structure. (Brinkmann, Ehrenstein, Steinhilper 1994)

Connecting Elements Easy to Find

For damage-free disassembly it is imperative that connecting elements be easy to find. Connections that are not obvious, such as inside snap catches at the dividing surfaces of two plastic parts, should at least be marked. Connections that are not marked and are only visible and accessible after the removal of other components (such as stoppers, slides etc.) should be avoided.

Easy Access to Connecting Elements

The easiest way to loosen connections is with a one-axial linear or twisting motion. Therefore the connections should be accessible for a disassembly tool, axial to the disassembly direction.

Connections that are Easy to Loosen

Socket and screw connections are particularly easy to detach. If possible, rivet joints and adhesive or soldered connections should be avoided. To allow for reuse, at least important components (the engine block, for instance) should be removable without damage.

Low Number of Connecting Elements

The component structure, i.e. the complexity of a product, is a factor that is of great influence in many areas of industrial production technology responsible for technical and economic possibilities.

The expenditure of time and effort in disassembly depends largely on the number of connections and the types used. Both should therefore be reduced to a minimum. Within one type of connection, such as screw connections for instance, uniform screw heads should be used to avoid the need for changing tools during the disassembly process.

A practical measurement of the complexity of a product is the so-called 'medium degree of knots' index according to Czeranowsky. This index is calculated by relating the number of corners E(x) (= number of connections) to the number of knots V(x) (= number of components) according to the following formula:

$$d_m = 2 \cdot \frac{[E(x)]}{[V(x)]}$$

- **Low Number of Components**

  The number of components should be kept as low as possible in relation to the function they fulfil. This reduces the expenditure for disassembly and sorting.

- **Tools Needed Reduced to All-Purpose Tools**

  Connections should be designed in such a way that they can be loosened with the usual all-purpose tools, i.e. screwdriver, scissors or drill, because, considering the large product variety, recycling enterprises are not generally equipped with special tools. Especially suitable for disassembly are connections that can easily be loosened without tools.

- **Creating Good Conditions for Mechanical and Automatic Disassembly**

  Apart from a structure which lends itself to easy disassembly and the use of connecting elements that can easily be loosened, standardization of components and material marking must be considered. In addition, the different types of connections should be uniform.

Checklist P 7

Criteria for disassembly	relevant for the product	Characteristics	Rating (Tick off Characteristics) A	B	C	No data available
Structure	☐	Hierarchic structure	☐			☐
		—		☐		
		Complex structure			☐	
Detectability of connecting elements	☐	Visible	☐			☐
		Hidden with marking		☐		
		Hidden			☐	
Accessibility of connecting elements	☐	Axial access in disassembly	☐			☐
		Axial access		☐		
		Difficult to access			☐	
Loosening of connecting elements	☐	Damage-free loosening	☐			☐
		Loosening with damage of connection elements		☐		
		Loosening with damage of components			☐	
Number of connecting elements	☐	No connection elements	☐			☐
		Low		☐		
		High			☐	
Variety of connecting elements	☐	Uniform	☐			☐
		Uniform within connection types		☐		
		No standardization			☐	
Number of components	☐	Low	☐			☐
		Due to function		☐		
		High			☐	
Tool requirements	☐	No tools required	☐			☐
		All-purpose tool		☐		
		Special tools			☐	
Automation of disassembly	☐	Automatic disassembly	☐			☐
		Mechanical		☐		
		Manual disassembly			☐	

Evaluation

A = Ideal situation

B = Acceptable situation

C = Urgent need for action

LCD

Fig. 6.14. Checklist: Design for disassembly

6.8 Minimizing Harmful Substances

Environmental problems associated with products are due to a variety of materials that are potentially dangerous to health and the environment. Here, some criteria are presented for the prevention or reduction of these problems. With regard to complex products the following substances are relevant:

- Volatile organic compounds, mainly halogenated and halogen-free hydrocarbons.
- Harmful organic trace substances, such as dioxins and furans, PCB and polycyclic aromatic hydrocarbons, which have proved to be highly toxic and carcinogenic.
- Heavy metals (mercury, lead, cadmium etc.) and heavy-metal compounds.
- Air pollutants that form harmful residues in subsequently installed cleaning systems.
- Organic substances that are difficult to breakdown (e.g. PCB).
- Flame retardants on a halogen basis or antimon-III-oxide, which is suspected to cause cancer.
- Products that have harmful effects on the environment such as PVC and products containing CFC and CC.

☝ Minimizing or Avoiding Harmful Substances

Rules

Materials selected should not contain any substances which pose a danger to health and the environment during production, use, processing, reuse, incineration or dumping. The following table shows alternatives to those toxic materials that are often used in complex products (Table 6.2):

Table 6.2. Alternatives to substances that are hazardous to health and environment

Substance	Occurrence	Alternatives
Polybromine diphenyl ether (PBDE)	Flame retardants in plastics, conductor plates, electronic components	Steel , ceramic or copper-clad base, high heat-resistant paste such as amidine, colour concentrate for flame retardant compounds on a polyethylene base, inorganic phosphate or nitrogen composites
Polybromine Biphenyl	Flame retardants in plastics, conductor plates, electronic components	Steel , ceramic or copper-clad base, high heat-resistant paste such as amidine, colour concentrate for flame retardant compounds on a polyethylene base, inorganic phosphate or nitrogen composites
Antimon-III-oxide	Flame retardants in conductor plates, electronic components (as synergist)	Steel , ceramic or copper-clad base, high heat-resistant paste such as amidine, colour concentrate for flame retardant compounds on a polyethylene base, inorganic phosphate or nitrogen composites
PVC	Cable sheath	PS, PE, rubber, polyurethane
PCB	Dielectric in capacitor	electrolytic capacitor with ethyleneglycol or butyrolacton
CFC	Cooling agent for household appliances, 'partition gas' and insulation gas in cooling appliances	Butane/propane mixture in cooling devices
Cadmium	Stabilizer in plastics, galvanic coating of steel sheets, screw heads	Stabilizers on a cadmium/zinc base
Lead	Plastics, metal fillers	Solder paste, conductive adhesive, joint of metal fillers containing lead
Mercury	Batteries, relays and switches	Gas-filled switches, mercury-free batteries

Avoiding Particularly Harmful Substances

In general, the use of substances that are acutely toxic, carcinogenic or capable of causing genetic mutations should especially be avoided, as well as those substances that cannot or only very slowly, be broken down (persistent) or accumulate in the food chain. Information about toxic substances can be obtained from regulations on dangerous substances (e.g. MAC: Maximum Allowable Concentrations or Technical Index Values). The MAC is the highest allowable concentration of a substance (gas, steam or dust), in the air of a workplace which, according to current scientific knowledge, does not impair health or cause undue annoyance in the case of repeated or long run exposure. The Technical Index Values take into account materials that are carcinogenic or cause genetic mutations and cannot be considered within the framework of the MAC values as these effects can manifest themselves after many years. It has thus been difficult to establish threshold values.

MAC

Allowing for Easy Removal of Harmful Substances

Substances that are potentially harmful to health or the environment and pose a danger upon reprocessing or recycling (for example toxic, explosive or volatile substances) should definitely be marked and positioned in such a way that they can easily be separated from the product. It is furthermore essential that components containing harmful substances can be separated or emptied before reprocessing in order to prevent reusable materials turning into hazardous waste. It should, for example, be possible to easily and quickly separate cables for reuse or problematic material combinations for special treatment. This can be realized by applying, e.g. push-fit connections.

Checklist P 8

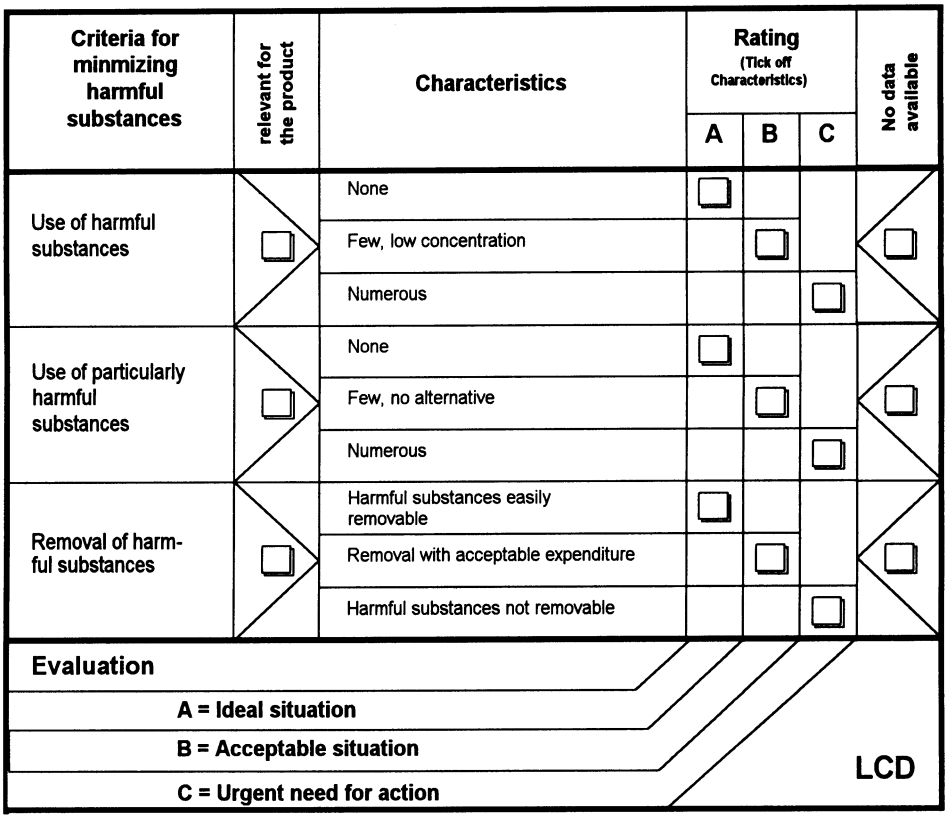


Fig. 6.15. Checklist: Minimizing harmful substances

6.9 Environmentally Friendly Production

Product concepts should be extended to include environmental aspects of the production processes involved. Processes are to be optimized and designed in such a way that waste, emissions and waste-water are largely prevented. Unavoidable substances that remain should be returned either directly to the production process by closed-loop circulation or by reuse in other industrial processes as raw or auxiliary materials (Fig. 6.16, p. 93).

☝ Choosing Production Processes with Minimal Waste and Recirculation

Rules

In principle, production processes should be chosen that generate little or no waste. Unavoidable production waste should be recycled with as little expenditure and value loss as possible. Difficulties arise especially with coated metal sheets and composite materials. One should consider coating metal sheets, for example, only after those production steps where waste is produced have been passed or by choosing coatings that do not impair recycling (see material compatibility).

Compared to household waste or bulky waste, production waste in general is easy to recycle. It can be separated and collected by material group or type. These opportunities should be taken.

☝ Minimizing Energy Consumption

Energy consumption is a main indicator of environmental pollution and should be reduced. There are many possibilities, ranging from energy-saving production processes, using waste heat to energy production in relatively efficient decentralized power plants. Even more environmentally friendly would be the use of solar cells on factory roofs for generating energy. 1200 square metres used for the collection of solar energy could save 100000 kWh and could thus reduce carbon-dioxide emissions by 100000 kg.

The most environmentally friendly ways of saving energy, however, are presented by the following examples:

- The use of waste heat from compressors for heating factory halls.
- The use of waste heat from the incineration of solvents by a varnish producer for heating phosphate baths.
- The use of heat pumps to recycle energy from production water to heating fresh water.
- Precise dimensioning of electric motors for injection-moulding machines.
- Improvement of insulation during maintenance work on buildings.

Minimizing Water Consumption

The economical use of water is an area of increasing importance. Savings can mainly be achieved through closed water-circulation systems. This requires a detailed registration of water consumption in the production areas of an enterprise, as this is the only way to discover a savings potential.

Preventing Hazardous Waste

Waste from industrial production has a high potential for containing hazardous substances which must be treated and disposed of in a special way. It can safely be assumed that, in the future, special wastes will become a serious cost factor in operational management, as disposal costs will increase owing to the limited waste-treatment capacities and dumping areas. Examples of hazardous waste are:

- Waste that contains oil.
- Paint waste.
- Waste that contains sulphur.
- Halogenic organic solvents.
- Mud and dust from steel works and blast furnaces.
- Salt slag.
- Halogen-free organic solvents.
- Filter and absorption masses.
- Mud and dust that contain heavy metals.
- Residues from chlorine chemistry.
- Inorganic residues from the chemical industry.

Preventing Emissions

Especially concerning air and water emissions there are many legal regulations which a company must comply with. This, however, is not enough from the point of view of the environment. Processing technology must be further optimized with the help of existing and

newly developed processes in order to further reduce emissions. In connection with this, it is very important that subsequently installed cleaning processes be replaced by integrated solutions so that unwanted emissions will not be generated in the first place.

A very good example is the coating of materials, a process which is of fundamental importance in many areas of production. At present, during industrial spraying, only 1/4 of the spray used actually remains on the work piece. The rest pollutes the environment in the form of solvent emissions and spray mud. An effective reduction of this environmental pollution requires integrated measures at the source. For this purpose, there are different technologies that can be employed:

Example spraying

- Spray cabins using recirculated air with only a small amount of fresh air added (effect: 80% emission reduction).
- Combinations of water-based spray with coating containing solvents (effect: 30% emission reduction).
- Electrostatic spraying by means of an electric field between the spray and the work piece (effect: 30-40% emission reduction).
- Automatic adjustment of the spray jet depending on the geometry of the work piece (effect: 10-15% emission reduction).

Avoiding Harmful Substances at the Workplace

It is important to make sure that, in production no substances harmful to health are emitted at the workplace. At the very least, the corresponding threshold values for the workplace (MAC-values) and the technical rules for hazardous substances (see design to minimize harmful substances) must be adhered to.

Checklist P 9

Criteria for environmentally friendly production	relevant for the product	Characteristics	Rating (Tick off Characteristics) A	B	C	No data available
Waste	☐	Waste-free production	☐			☐
		Little waste, waste recyclable		☐		
		High amount of waste, little or not suitable for recycling			☐	
Energy consumption	☐	Energy-saving production / use of waste heat	☐			☐
		Energy-saving production		☐		
		High energy consumption			☐	
Water consumption	☐	Water-saving production / circulation	☐			☐
		Water-saving production		☐		
		High water consumption			☐	
Hazardous waste	☐	None	☐			☐
		Little, easy to control		☐		
		High			☐	
Emissions	☐	None	☐			☐
		Low through integrated solutions		☐		
		High			☐	
Harmful substances at the workplace	☐	None	☐			☐
		Adherence to MAC-values		☐		
		Exceeding threshold values / carcinogenic substances			☐	

Evaluation

A = Ideal situation

B = Acceptable situation

C = Urgent need for action

LCD

Fig. 6.16. Checklist: Environmentally friendly production

6.10 Minimizing Environmental Impact of Product in Use

In the usage phase, many products that require consumables such as electricity, water, chemicals, detergent, paper etc., often have a high environmental impact. This is the case, for instance, with washing machines or dishwashers. For colour TVs the energy consumption during use is 5 times higher than the energy use in production. The product-design should therefore emphasize the economical use of energy, water and other auxiliaries during operation, if possible, without emission of harmful substances (Fig. 6.17, p. 100).

☝ Minimizing Energy Consumption

The goal should be to develop low-energy devices that have minimal energy requirements both in use and in stand-by mode.

Stand-by television

A German manufacturer of colour TV sets, 'Schneider Elektronik Rundfunkwerk GmbH' has developed a special energy-saving switch that operates on the principle that watching TV in the dark requires less contrast. The use of the energy saving switch halves the maximum energy consumption. This is achieved through two features of the circuitry, by which the electricity use for and the output of the loud speaker are reduced.

For the stand-by mode of television sets, the usual 4–15 W power input can be reduced to less than 1 W.

Computer

Computers, monitors and processors should be equipped with an energy-saving self-activated resting mode. Here, the American threshold value of the STAR energy programme could serve as a standard. The power input should be 30 W maximum.

Vacuum cleaner

The German company AEG Hausgeräte, in Nuremberg, has reduced the energy consumption of its vacuum cleaner, the 'Öko-Vampyr' by 30%. This was achieved by optimizing its turbine: with a power input of 750 W the same suction capacity was realized as previously with 1100 W.

For cookers equipped with a divider in the oven section, as developed by AEG, electricity consumption was reduced by 20%, as only that part of the oven is heated that is actually used. In the stove area, heat is produced directly by induction in the bottom of a cooking pot, which also reduces energy consumption.

Table 6.3 shows consumption values of optimized household and office appliances that should be regarded as minimum standards:

Table 6.3. Consumption values of optimized household and office appliances

Product	Energy values	Water values	Information
Washing machine	1.7 kWh[a]	53 l[a]	AEG Öko-Lavamat
Cooling appliance	0.44 kWh[b]		AEG Öko-Santo Super
Dishwasher	1.1 kWh[c]	15 l[c]	AEG Öko-Favorit
Colour TV	Stand-by 1 W		LOEWE Opta Prototype
Vacuum cleaner	750 W[d]		AEG Öko-Vampyr
Personal computer	Stand-by < 30 W		Siemens-Nixdorf
Laser printer	Stand-by 10 W, Printing 180W		Hewlett Packard

[a] With 5-kg washing load.

[b] Table refrigerator with (Tristar-) deep-freezing compartment, for 130 l.

[c] Consumption values for normal programme at 65 °C.

[d] Nominal power input, effective suction power 240 W.

Minimizing Water and Consumables

The reduction of water consumption of washing machines and dish washers should be considered. By optimizing the water consumption of washing machines it has been continually reduced over the past few years. Today, washing machines use only half the amount of water required in machines produced 10 years ago.

Fuzzy logic

In washing machines and dishwashers, the amount of washing powder and rinsing agent should be reduced. Here, the application of 'fuzzy logic' offers new possibilities, whereby the programmes of the appliances can be designed in such a way that if the machines are not fully loaded, they only use as much water and energy as is actually required for washing the clothes or the dishes. It would be better still if the consumer acted thoughtfully: one full load takes less energy and water than two partial loads.

Preventing Emissions that are Harmful to Health

Flame retardants

When in use, appliances should not present any danger to health. The emission of substances that are harmful should therefore be avoided. Some flame retardants which present a health hazard, such as polybrominated diphenylether and polybrominated biphenyl, have been found in electronic appliances. In the case of a household fire, extremely toxic dioxins and furans could be produced, in which case the remains of a household fire would have to be disposed of as special waste.

Consumer Information for Environmentally Friendly Use

The manufacturer should point out to the customer how environmental pollution during the use of the product can be reduced (e.g. by energy-conscious operation). Advice should be included on the reuse and disposal of the appliance. Instructions for the use of the product should address the fact that the appliance constitutes valuable material resources, and that it should be returned to either the manufacturer the dealer or the waste contractor.

Checklist P 10

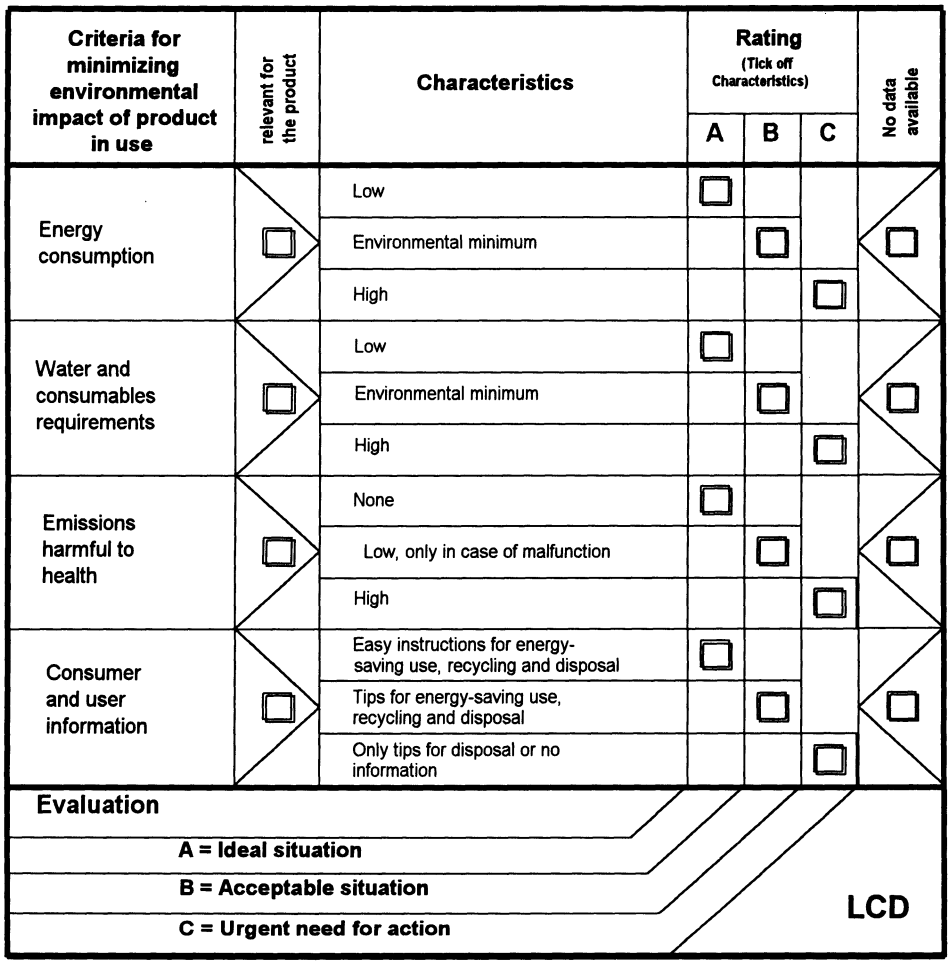


Fig. 6.17. Checklist: Minimizing environmental impact of product in use

6.11 Using Environmentally Friendly Packaging

Packaging contributes substantially to the solid waste problem in Europe. Given its significance, it is imperative to understand the function of packaging and its relation to products. Product-design procedures for the inclusion of environmental criteria as part of a holistic approach should include packaging.

Environmental benefits

The main benefit of using environmentally friendly packaging is waste reduction, which contributes to resource conservation and pollution prevention. An optimal packaging design combines highly functional and minimal package waste criteria. In other words, it combines product protection and environmental preservation. In order to improve packaging design by optimizing its function and minimizing the environmental and economic costs, design criteria have been studied and applied, in particular those for material selection.

Decision-makers considering package design must address factors related to the environment and to functions at four different levels. These levels could be considered as a hierarchical analysis in which the designer can set priorities for environmental criteria that are important to the design process (Fig. 6.18, p. 105).

The assessment levels of environmentally friendly packaging are the following and will be described below:

- No packaging
- Multiple-use packaging
- Returnable packaging
- Packaging design criteria

No packaging

No Packaging: The first step is to think about the packaging concept itself and to question the very need for it. This includes a study of the function of packaging and various options to avoid it while ensuring the protection of the product, which is the main reason for using packaging.

Multiple-use packaging

Multiple-Use Packaging: The packaging efficiency function can be maximized by applying the multiple-use packaging concept for the optimization of product transport. The goal of this concept is to extend the service life of the packaging by using it for other purposes than transport of end products only. The concept also constitutes an effort to integrate closed-loop procedures into the design of packaging. The application of multiple-use packaging can be realized by combining the dual function of multiple-object transport and ensuring product protection.

Returnable packaging

Returnable Packaging: The introduction of returnable packaging is intended as a measure to prevent the generation of packaging waste. Returnable packaging involves a system in which the returned packages are reused for the same function as their original one. The use of deposit systems or take-back systems should always be considered in advance. Companies are increasingly becoming interested in these systems. Automobile manufacturers, for example, are requiring their suppliers to take back their packaging materials.

Choosing Reusable Packaging

The durability of used packages depends on the physical properties of the materials used. It is also the main factor for repeated reuse. The concept of durability should include the physical properties of the materials such that after use of the package, the original protective packaging function is maintained. The packaging design process must balance light weight and durability in order to produce a package that is both light and strong enough to absorb shock impact and to allow its reuse.

Packaging design criteria

Packaging Design Criteria: As the social demand for products that conserve energy and resources is steadily increasing, the packaging industry must continue to respond by developing packaging which is better reusable and recyclable and made with less material, which is also non toxic. These efforts are also referred to as 'source reduction'. Being a combination of the reduction of materials, pollution, energy and financial costs, reducing and controlling packaging waste disposal is an extremely important effort.

Reducing Weight/Volume

'Light weight' refers to less material being used and often also implies lower transport costs. Reducing the weight of packaging has two direct, positive effects: it contributes to the conservation of limited resources and it decreases the amount of waste generated. Indirectly, positive effects also arise from the fact that less material produced also means that fewer pollutants have been generated and energy has been conserved. Reduced material and energy use leads to economic savings throughout the product life cycle.

When reducing packaging waste, it is more important to know the weight of the packaging than its material composition. Therefore, paper, metal foils, plastic or plastic films are generally better than containers as the latter tend to be heavier. For example, plastic diaper packaging presents 80% less weight and volume than cardboard boxes.

In addition, the reduction of secondary packaging can also lead to important packaging reduction.

Avoiding Harmful Substances

Corrugated paperboard and polystyrene foam are used to protect electronic equipment against damage during transport. These materials hold items securely in their cartons and cushion them against falls, shifts or bumps. Prior to transport the cartons are usually stacked on pallets and wrapped with a sheet of self-clinging stretch wrap, to prevent shifting and falling.

It is necessary to check all these packaging materials as to whether polluting substances may have been used. For the purpose of shifting towards environmentally friendly packaging materials, toxic additives such as heavy metals (Pb, Cd, Hg and Cr) must be banned. The main focus here is to prevent the emission of hazardous substances into the environment, either in their original or in a modified chemical form, during waste treatment. The key for choosing materials for environmentally friendly packaging lies in the use of biodegradable materials based on renewable resources, which can reduce the impact on the environment.

Use of Recyclable Packaging

Among the most important factors in material selection for packaging is its recycling potential. The use of plastic materials in packaging has consequences for the environment, both in the short and the long term. Different plastic types must always be identified because of their possible incompatibility in recycling processes. A procedure is required for the screening of the collected plastics as to their suitability for recycling.

Use of Recycled Packaging

A reusable package cannot last forever. Final disposal of packaging can be prevented by recycling the constituent materials. The recycling process facilitates reintroducing the packaging materials into the production system, thus extending the life cycle of those materials. Recycled materials should always have the same quality, however, as those produced from virgin raw materials.

Use of Biodegradable Materials

Biodegradation is a natural process which involves the breakdown of organic matter. If biodegradable materials based on renewable resources are selected for packaging, then the disposal process will deal only with harmless materials that can easily be converted. It would be a very good solution to have a waste treatment system that was suitable for the material properties. If the recycling process is not appropriate for certain materials, then the use of alternative biodegradable materials might be a good solution, as a waste product could potentially be reclaimed.

Checklist P 11

Criteria for using environmental friendly packaging	relevant for the product	Characteristics	Rating (Tick off Characteristics) A	B	C	No data available
Packaging definition	☐	No need for packaging	☐			☐
		Multi-use packaging adopted		☐		
		Improvements in the packaging design criteria			☐	
Returnable packaging	☐	Existing system	☐			☐
		Possible implementation		☐		
		Not possible			☐	
Reuseable packaging	☐	Already reuseable	☐			☐
		Partially reuseable		☐		
		Not reuseable			☐	
Take-back-- package system	☐	Existing system	☐			☐
		Possible implementation		☐		
		Not possible			☐	
Weight/volume reduction	☐	Obvious reduction	☐			☐
		Possible reduction		☐		
		Reduction not possible			☐	
Harmful substances on packages	☐	None	☐			☐
		Few		☐		
		Numerous			☐	
Recyclable packaging	☐	High quality recycling	☐			☐
		Low quality recycling		☐		
		None			☐	
Use of recycled materials	☐	High percentage	☐			☐
		Medium/low percentage		☐		
		New materials			☐	
Use of biodegradable materials	☐	Biodegradable packaging	☐			☐
		Some biodegradable		☐		
		None			☐	

Evaluation

A = Ideal situation

B = Acceptable situation

C = Urgent need for action

LCD

Fig. 6.18. Checklist: Using environmentally friendly packaging

6.12 Environmentally Friendly Disposal of Nonrecyclable Materials

Apart from waste prevention and recycling, environmentally friendly design also includes ensuring that substances that cannot be reused or that might pose waste disposal problems will eventually be disposed of in an appropriate manner. Despite strategies for prevention or reuse, a certain percentage of waste will always remain that must be disposed of through dumping or incineration. Also, from the consumer's point of view, it cannot be assumed that all products that could be reused or recycled are actually returned for that purpose. They will therefore end up at a dumping site or in an incinerator (Fig. 6.19, p. 104).

Avoidance of Hazardous Substances During Disposal

Rules

Dumping or incineration should not set substances free that could be harmful to the environment. This means that, as early as the planning phase, the use of substances such as PVC, heavy metals used in colour pigments for plastics, batteries and accumulators as well as flame-retardant coatings should be avoided.

Guarantee for Natural Compatibility

The final waste that is free of toxic substances should easily be integrated into the natural bio-geological material cycles. The ideal solution would be to use construction materials and additives that are biodegradable and compatible with those found in nature.

Checklist P 12

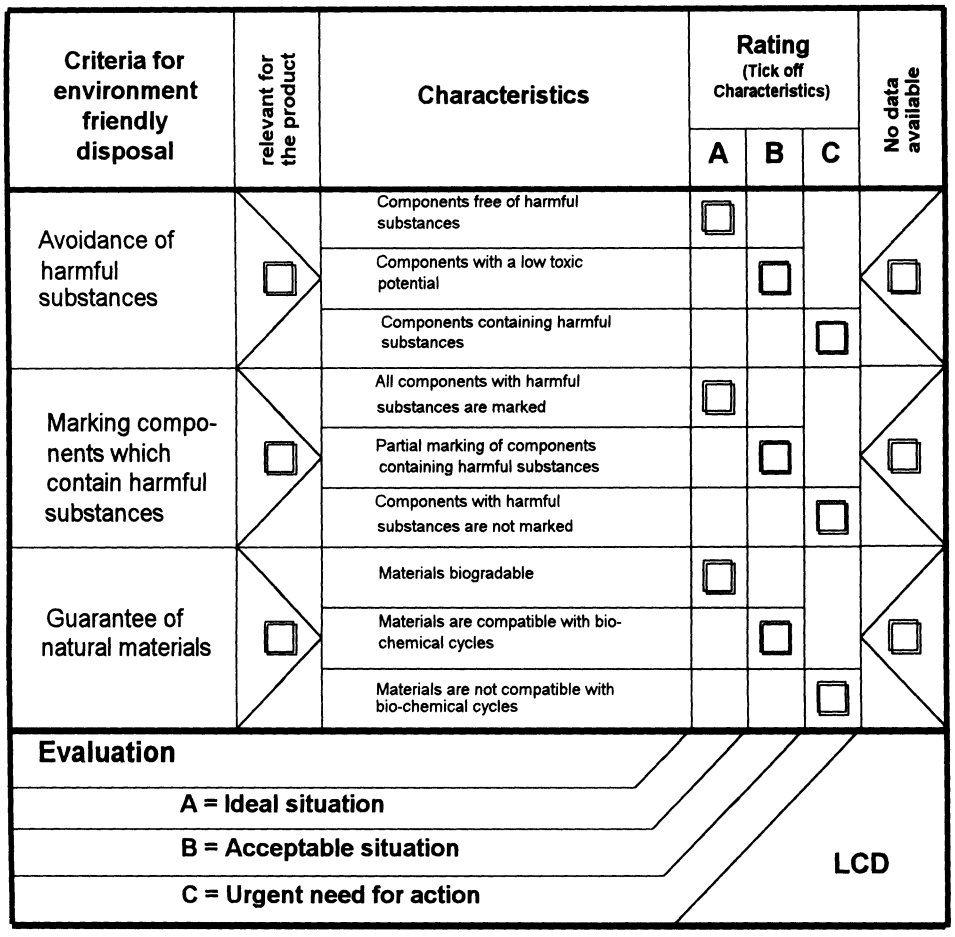

Criteria for environment friendly disposal
relevant for the product
Characteristics
Rating (Tick off Characteristics)
A
B
C
No data available
Avoidance of harmful substances
Components free of harmful substances
Components with a low toxic potential
Components containing harmful substances
Marking components which contain harmful substances
All components with harmful substances are marked
Partial marking of components containing harmful substances
Components with harmful substances are not marked
Guarantee of natural materials
Materials biogradable
Materials are compatible with bio-chemical cycles
Materials are not compatible with bio-chemical cycles
Evaluation
A = Ideal situation
B = Acceptable situation
C = Urgent need for action
LCD

Fig. 6.19. Checklist: Environmentally friendly disposal of nonrecyclable materials

6.13 Implementing Environmentally Friendly Logistics

In the long run, increasing environmental pollution as well as capacity constraints within the transport system will require companies to rethink their transport policies in one way or another (Fig. 6.20., p. 113).

Traffic causes pollution. The most important issues in this field are:

- Emissions of pollutants.
- Energy consumption.
- Noise.
- Safety.
- Land use.

However, it is not only the use of vehicles that causes environmental problems, but also their production and disposal, including that of the traffic systems they use.

Forecasts

Forecasts have shown that transport volumes will increase enormously in the future. According to an estimate by the German Department of Transport, for example, by the year 2010 Germany must reckon with an increase in rail transport of 30%, road transport of 41% and inland waterway transport of 20%. Therefore, pollution prevention must focus on the distribution aspect of products as well.

Integrating Transport into the Company's Environmental Policy

Rules

For many organizations environmental awareness stops at the fence of the production site. It is not easy to take responsibility for the stages beyond production. Organizations argue that they have limited influence on their suppliers and retailers. Limited influence is still some influence, however, the extent of which depends on one's market position and on the possibility of organizing joint activities.

The EMAS regulation on environmental management also addresses the impact of transport as an element of environmental policy and of a programme for pollution prevention. It is obvious that, for an assembly plant especially, the main environmental impact arises not so much from the production at site, but rather from the just-in-time logistics of materials and components and from the worldwide distribution of the final product.

Selection of Suppliers

Environmental logistics has to do with the selection of regional suppliers and reuse and recycling companies. Especially in consumer

electronics, raw materials are delivered from all over the world. After assembly the product is distributed all over the world. The collection of used products for recycling purposes may also be organized on a worldwide basis. Therefore, regional production sites would be an opportunity to increase the life span of the product and reduce the impact of transport.

Selection of Transport Modes

In choosing the most suitable transport mode, thought should be given to the fact that the environmental impact of ships and trains is substantially less harmful than that of trucks. In a study on freight transport on the Danube river, carried out by Hiess and Korab for the WWF in 1992, the average pollution loads were presented as follows (Hiess and Korab 1992):

Table 6.4. Air pollution loads in g/tkm.

Pollutant	Road	Rail	Ship
Toxic air pollutants:			
CO (carbon monoxide)	2.768	-	0.556
H_xC_y (hydrocarbons)	0.830	-	0.167
NO_x (nitrogen oxides)	6.920	0.006	1.390
PM (particulate matter)	0.623	-	0.125
Nontoxic air pollutants:			
SO_2 (sulphur dioxide)	0.346	0.007	0.070
CO_2 (carbon dioxide)	193.760	4.080	38.920
TOTAL	205	4	41
Relative pollution load	51	1	10

Another aspect is the avoidance of delivery trucks returning empty to the production site. In some countries only professional trucking organizations are allowed to combine different loads. Their efficiency is much better than that of a company's internal delivery schedule from the production site.

Integrating an Ecologistics Concept

The reintroduction of used goods into industrial material cycles requires additional transport services. If the transport volume required for the return of used goods is as large as that for the delivery of goods to the final consumer, this would most probably bring the transport system to a standstill.

Therefore, the procurement, distribution and return of goods must not be organized separately but be coordinated within one integrated concept of ecologistics. It also makes sense to cooperate with forwarding agents, who will ship transport packaging back to the enterprise.

At the moment environmental considerations do not play a decisive role in the design of a firm's transport system. Factors such as economic efficiency, speed, reliability (punctuality), flexibility, costs, etc. predominate.

Economic efficiency is taken to be the single most important factor, whereas reduced environmental impact is regarded as an additional benefit. The main criteria for the environmental soundness of transport systems are safety, energy consumption, emission of pollutants, noise and land use.

Just-in-time concepts

In order to optimize the flow of materials through the enterprise and to reduce stocks as much as possible, many enterprises make use of just-in-time concepts (JIT) offered by suppliers and by forwarding agents. Only those materials are delivered that are needed at a certain stage of the production process. This, however, requires the optimization of internal processes and the long run planning of production, including a forecast of material needs. If these requirements cannot be met, the time allowed for external transport will be too short and the latter cannot be optimized with regard to capacity utilization and return freight.

Distribution centres and buffer stocks facilitate the optimization of transport systems. The forwarding agent arranges the delivery of the goods to e.g. a railway station, then the goods are transported by rail over a major part of the distance to other distribution centres, from where distribution will again be handled by a forwarding agent.

The implementation of environmental transport management can vary considerably from one firm to the other and is primarily dependent on the organization of the firm's logistics.

Relevant Criteria for the Fleet of Vehicles

The following criteria are, among others, relevant for enterprises that have their own fleet of vehicles:

- Use of lorries equipped with pollution and noise-control devices.
- Good maintenance of the fleet.
- Use of fine oil filters to reduce consumption.
- Use of software for the optimization of transport systems.

Relevant Criteria for the Choice of a Forwarding Agent

For those who use the services of a forwarding agent, the following measures are of particular importance:

- Reduction of packaging.
- Reduced and optimized use of JIT (just-in-time).
- Long run planning in the field of logistics.
- Acceptance of higher prices for environmentally sound transport systems.
- Selection of forwarding agents according to environmental criteria (For example: Do they use low-emission vehicles? Do they use appropriate systems to optimize routes? Do they give advice on environmental matters ?).
- Optimized use of vehicles: combined transport (rail/road. inland waterways/road), return-freight, optimization of routes, optimization of loading space, communication.
- Use of distribution centres.
- Use of containers appropriate for rail transport.

Basically it can be said that every firm can benefit from recording all transport movements and analyzing them with a view towards environmental optimization. Forwarding agents and experts offer consulting services in the field of environmental optimization of logistics. In addition, a wide range of software for transport systems optimization is available.

Transport of Employees

Another essential factor in the field of ecologistics is the transport of employees to and from their place of work. There are different options for the employer to encourage employees to leave their private cars at home. Cases in point are:

- The use of plant-owned buses.
- Incentives for employees to use public transport systems, e.g. by

partly financing yearly tickets for public transport.

- Incentives for employees to go by bicycle. Giesinger and Kopf, a company producing all kinds of packaging in Austria have, for example, organized a 'cycle lottery'. Once a week (summer or winter) one employee is selected at random and if he or she has come to work by bicycle on that particular day, he or she will receive a certain amount of money. If not, the latter will be added to the jackpot for the following week.

Checklist P 13

Criteria for implementing environmentally friendly logistics	relevant for the product	Characteristics	Rating (Tick off Characteristics) A	B	C	No data available
Importance of transport within the company's environmental policy	☐	Integrated in the company's environmental policy	☐			☐
		Partly taken into account		☐		
		Not taken into account			☐	
Vehicles used	☐	Consideration of ecological criteria (low-emission lorries, fine oil filters)	☐			☐
		Measures taken to reduce fuel consumption		☐		
		No environmentally relevant investigation			☐	
Selection of suppliers	☐	Regional supply and disposal	☐			☐
		Supra-regional supply and disposal		☐		
		Global supply and disposal			☐	
Selection of transport modes	☐	Rail or ship	☐			☐
		Combined transport		☐		
		Road transport			☐	
Return	☐	Avoidance of unloaded trips by making use of shipping exchanges	☐			☐
		Unloaded trips are the exception		☐		
		Unloaded trips are not important			☐	
Eco-logistics concept	☐	Long-term planning - no JIT system	☐			☐
		Intermediate storage in warehouses or distribution centres		☐		
		JIT - system			☐	

Evaluation

A = Ideal situation

B = Acceptable situation

C = Urgent need for action

LCD

Fig. 6.20. Checklist: Implementing environmentally friendly logistics

7 Trade-Offs Between Criteria

7.1 Introduction

When environmental principles and criteria, as presented in Chap. 6, are taken into account in the product-design process, this often leads to conflicts and evaluation problems in practice. One common example is the choice of materials without harmful substances versus the need for flame retardants because of fire-safety requirements. Components such as printed circuit boards made from thermo-setting plastics, plastic back walls of TV sets or computers, and casing parts with ventilation slits are required to contain flame retardants. These substances are not only classified as highly toxic and harmful but also impair material recyclability.

A strategy for minimizing the environmental impact is to find a compromise whereby fire safety is maintained but harmful substances are replaced by harmless materials. It is possible, for example, to meet the required fire safety standard for plastic casings without using flame retardants by using reinforced walls, modified injection moulding, metal fillers that are more resistant to corrosion and optimized circuit layouts that are less susceptible to failure. Replacing flammable materials with steel, for instance, does not present a problem, either. Steel has already been used for casings of television sets. Printed circuit boards do not require flame retardants if the easily flammable thermo-setting plastics are replaced by ceramics or copper foils (an example is the 'green' television set by Loewe).

Environmentally oriented systems

Such conflicts exist not only between environmental and technical (as above) or economic requirements (dealt with in Chap. 9), but also emerge within environmentally oriented systems.

This chapter deals with the new trade-offs between criteria that the designer will be confronted with. They present a real challenge in ecodesign since not much experience has as yet been gained in this field nor is there a good information basis. The following chapter is an attempt to explain the most important trade-offs between criteria that arise in the development and design process and to point to possible solutions.

7.2 What Trade-Offs Can Arise?

Some conflicts that often arise and play an important role in the design process are:

Use of recycled materials	vs	Use of materials without harmful substances.
Material input	vs	Repair-friendliness and resistance to wear and tear.
Material input	vs	Recyclability.
Use of renewable materials	vs	Recyclability.
Increasing product durability	vs	Energy, water, material consumption.
Recyclability	vs	Vehicles used for transport.

P 2 vs P 8

- **Use of Recycled Materials vs Use of Harmful Substances**

On the one hand, the use of recycled materials is essential for closing material cycles and should therefore be given considerable thought. On the other hand however, recycled materials may contain harmful substances so that their use in new products might be out of the question, for health as well as environmental reasons (for example lead and cadmium in recycled plastics).

In this case, a choice has to be made between harmful recycled materials and primary raw materials that have low concentrations of harmful substances or contain none at all. In order to avoid this conflict, the product-designer should see to it that materials without harmful substances are used, as this provides the only solution to the problem in the long run. In the short run, materials or components that contain particularly harmful substances must be removed from the material cycles. They will then receive special treatment or will, if that is impossible, be dumped. Any other procedure would make an otherwise attractive recycling activity doubtful because of the accumulation of harmful substances in the product.

P 2 vs P 4

- **Material Input vs Repair-Friendliness**
- **Material Input vs Resistance to Wear and Tear**

The miniaturization of products, component groups or components allows savings in material use and thus in resources, and could lead to a reduction in the application of harmful substances. However, the components may not be easy to repair. Electronic components, for

example, in surface-mount-technology (SMT) do not require much material, but replacing a condensator would not make economic sense. Therefore, rather than taking out an individual component, the whole printed circuit board will be replaced. The best environmental strategy can be found by making use of material balances.

In general, single-material use is good for future recycling. However, choosing one material rather than a variety of materials, may lead to increased wear in mechanical parts such as bearings, rollers or ducts in vacuum cleaners. A solution to this conflict could be to practice design for disassembly and to choose materials that are compatible in recycling. In this way, the materials can be separated according to material groups and can be reused without loss of quality.

P 2 vs P 6

- **Material Input vs Recyclability**

A reduction in the amount of material used may also affect product recyclability, e.g. if more complex materials are chosen such as fibre-reinforced plastics. Here again, life cycle assessment can support the decision as to what strategy to follow. Volvo, for instance, used LCA to conclude that the reduction in the weight of the dashboard of one of its models, rather than making it recyclable, was the best way to environmentally optimize the car. The reason was that this would lead to significant savings in fuel consumption during the life span of the car (see Chap. 8).

P 3 vs P 6

- **Use of Renewable Resources vs Recyclability**

The objective to use renewable resources can be in contradiction to the recyclability of materials as a prerequisite for industrial material cycles. This is the case when a renewable material, such as wood, for instance, contains additives or has had surface treatment. In this case, high-quality recycling is often no longer possible. Furthermore, chemical additives can lead to problems upon disposal.

Here again an ecobalance can provide the necessary information as to the best strategy. Generally, the evaluation of renewable resources depends on the forestry and agricultural methods employed. The environmental advantages of renewable resources come into full play when there is a lasting cultivation which does not require much energy, fertilizers or pesticides which might harm the soil or ecosystems. If these conditions have been fulfilled and the renewable materials have not become harmful through processing or improvement, then, from an environmental point of

view, materials based on renewable resources present an interesting alternative to nonrenewable raw materials.

P 4 vs P 10

- **Increasing Product Durability vs Energy Consumption During Use**
- **Increasing Product Durability vs Water and Auxiliary Material Requirements**
- **Increasing Product Durability vs Emissions Harmful to Health**

Increasing the life span of a product might prevent the integration of possible innovations that could reduce environmental impact. In the case of washing machines and dish washers, for example, one would have to look at the saving of resources due to increased durability and compare that to the environmental pollution due to the consumption of energy, water and chemicals during the use of the product, which may become too high as more efficient products are introduced.

Only by taking all product life phases into account will it be possible to assess which strategy is more environmentally friendly. An energy-saving refrigerator, for instance, with a daily saving of 0,30 kWh is - in comparison to an old appliance - more favourable to the environment only after at least 4.5 years of use. Not before that time is the energy used to make the new refrigerator compensated for by the energy-saving during its use. The situation with personal computers, however, is a different one. Here, a compensation is not possible since the saving of electric energy during the use of a green PC with integrated power-management is rather low compared to the energy used for its manufacture. In this case, priority should be given to increasing the life span rather than to saving energy during use.

P 6 vs P 13

- **Recyclability vs Vehicles Used for Transport**

The return of products into industrial cycles, as opposed to their dumping or incineration, is always connected with higher energy expenditure because of the additional transport. It is likely that this additional energy consumption is higher than the saving achieved in recycling as compared to the extraction of primary materials. The shorter the life of a product and the more intensive its turnover, the more important the energy consumption by transport will be. In order to find out which strategy is best, rough calculations of the energy flows along the product life cycle will provide the necessary data. If collection logistics are to be developed,

attention should be paid to the fact that they can result in energy and resource savings.

7.3 How to Solve These Conflicts

At first glance, it appears that the conflicts between different criteria can hardly be resolved. In practice, continuous efforts will have to be made to find compromises. Solutions can only be found in the respective context of the product-design. Therefore, general recommendations cannot be given.

In any case, the decision must respect both the environmental objectives of the company and the priorities of the relevant national environmental politics. For the company, it could be more important in a given period of time, for example, to minimize emissions and harmful waste and/or to minimize raw materials consumption. It might, however, also be important to increase recyclability and/or to minimize waste-treatment costs, whereas others may focus on having the European ecolabel on their products, etc. At the international level, it is important to consider the waste-management laws as well as other characteristics in all countries that are relevant to the life cycle of the product, especially the country where the product is going to be sold. Here important factors might be: high incineration costs, high landfill costs, high recyclability rates, presence of reuse and recycling schemes, national ecolabels and high environmental consumer awareness.

In order to resolve trade-offs between criteria, it is not possible to suggest any single tool for prioritization, because it depends on the product. In fact, different complex products have different life cycles and for each product life cycle one must consider different environmental problems, stage by stage (e.g. resource depletion, greenhouse effect, ozone layer depletion, acidification etc.). However, obtaining sufficient information is a necessary requirement as well as finding balances between different issues. Life cycle assessment as well as other assessment tools can help to point to conflicts between criteria and can provide information about the product life cycle. They are therefore particularly well suited for resolving conflicts between environmental criteria (see Chaps. 5 and 8).

Decisions for the resolution of trade-offs can be made or compromises found on the basis of the factual information they provide, in connection with the political goals referred to above and in consideration of the rational, subjective and political effects influencing the prioritization of problem solving. Often enough, rough estimates with regard to energy and material flows can be made without great expenditure and thus

sufficient information can be made available for assessing the environmental optimum. The objective, however, should not be finding the smallest common denominator in environmental terms but rather developing innovations in order to fully resolve the conflicts. Compromises always present second-best solutions. Innovations, on the other hand, are all-encompassing solutions in the life cycle of products that provide a complete resolution of a conflict.

8 Environmental Assessment Tools

8.1 Introduction

As referred to in Chapter 5, other tools than those presented in Chapter 6 are available to the designer at different stages of the product development process. Chapter 7 presented new kinds of conflicts that designers must deal with. As a sound way to solve those conflicts, it emphasized the importance of assessing alternatives, considering all stages of the product life cycle.

This chapter presents the principles of life cycle thinking and, in a very concise way, two environmental assessment tools for the study of the product throughout its life cycle. The first tool presented is life cycle assessment (LCA), a mainly quantitative tool, and the second is the product summary matrix, a more qualitative and faster tool.

8.2 Principles of Life Cycle Thinking

Life cycle thinking is the essence of ecodesign. The product has environmental effects not only during manufacturing, but also before and after that important stage. Considering the environment involves what happens from the product's 'birth' till its 'death'. In other words, any product has environmental influences from 'cradle to grave'. The whole product life cycle must be considered (Fig. 8.1, p. 118).

By applying a life cycle approach in product development, the aim is mainly to answer one or both of the following questions:

- What are the most important environmental problems of a product?
- What is the best solution?

Qualitative LCA

Qualitative LCAs are already being used by an increasing number of companies to provide preliminary insights into the environmental aspects of a product. However, in order to determine more definitively whether one product is 'greener' than another, it is also necessary to know how quantities should be weighted, to reflect their relative health and environmental risks. For example, how should a pound of sulphur dioxide that is emitted into the air during production, be compared to a pound of solid waste going to a landfill? To resolve such questions, additional

information at the least about environmental fate, exposure pathways and dose-response data for each environmental release are required.

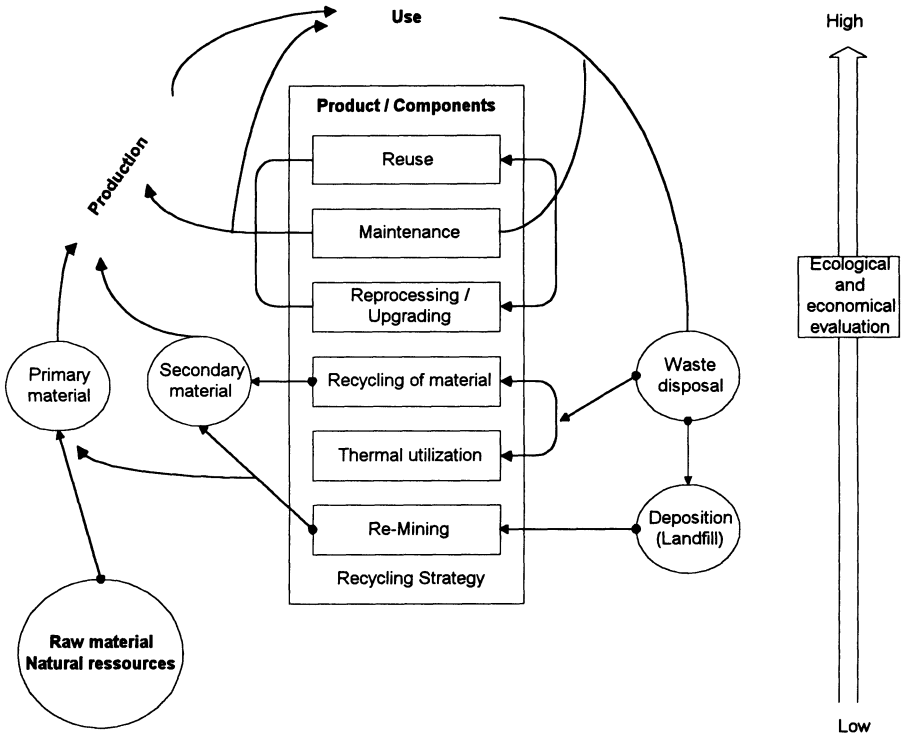


Fig. 8.1. The product life cycle. (VDI-Nachrichten 41/1995)

Generally speaking, qualitative approaches are very useful at the beginning of the product development process. As the analysis becomes more detailed, quantitative approaches provide better support. However for every method the use of common sense is highly recommended: it is very time-consuming, for example, to perform detailed LCAs for 20 different materials or components of a complex product.

The most important result of the use of life cycle thinking is the assessment of the whole product life cycle. Even without making a complete LCA, life cycle thinking or life cycle design can lead to important new insights.

Conceptually, the life cycle approach has helped to illuminate the environmental impacts of some products that had not been considered before, especially the 'upstream' impacts associated with material extraction and processing. By means of comprehensive accounts of material inputs and outputs, the life cycle approach can keep track of impacts that have merely been shifted from one stage of the life cycle to

another. The general categories of environmental impact to be considered include resource use, human health and environmental health (Peneda 1995).

Example: dashboard

- For the optimization of the NedCar dashboard, Volvo used LCA to conclude that the best way to achieve this was to reduce the weight of the dashboard as well as to reduce the consumption of electricity by the ventilator. Every kilogram added to the weight of the car leads to the consumption of an extra 5–10 l of fuel throughout the life cycle of the car. The study also showed that every watt of electricity produced causes the consumption of 3–5 l of fuel. Optimization of the weight and radiator efficiency could lead to savings of more than 50 l of fuel throughout the life span of the car.
- According to Goedkoop, the burning of one litre of fuel is more environmentally dangerous than the production of a kilo of plastic, therefore, the benefits of the measures mentioned were more important than making the dashboard recyclable (Goedkoop 1994).

8.3 Life Cycle Assessment

If more detailed insights are required, more complete LCA methodology must be applied. LCAs attempt to measure the 'cradle-to-grave' environmental impacts of a product. In principle they could be used in the design process to determine which of several designs may leave a smaller 'footprint' on the environment or after the fact to identify environmentally preferable products e.g. in government procurement or ecolabelling programmes.

As defined by ISO 14040, "LCA is a technique for assessing the environmental aspects and potential impacts associated with a product, by:

- Compiling an inventory of environmentally relevant inputs and outputs of a system.
- Evaluating the potential environmental impacts associated with those inputs and outputs.
- Interpreting the results of the inventory and impact phases in relation to the objectives of the study."

LCA is a dynamic and iterative assessment process, which consists of four interrelated phases: goal and scope definition, inventory analysis, impact assessment and interpretation of results (Fig. 8.2, p. 120).

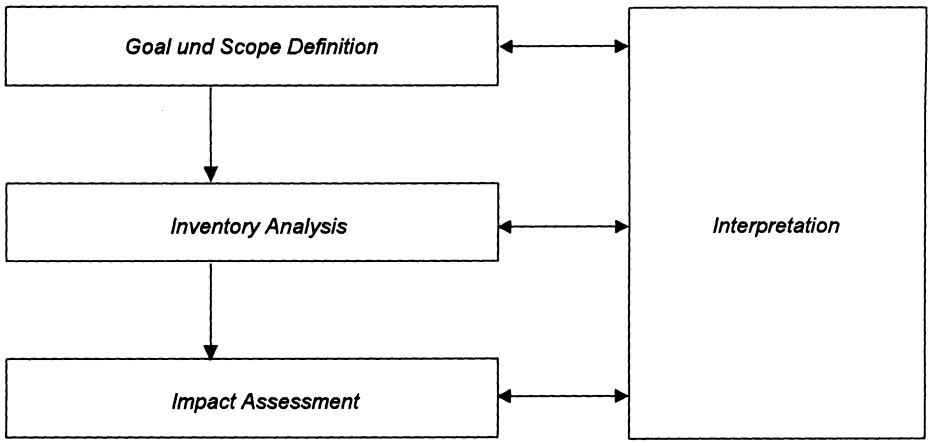


Fig. 8.2. Life cycle assessment methodology. (Draft ISO 14040)

Limitations

It must be stressed, however, that LCA, as a new tool for the study of the environmental influence of a product, still has a number of limitations, for example:

- LCA is not a mature tool: work on standardization methods is at present in progress within the ISO. As several different variants of assessment methods are currently in use, it is difficult to compare the results of different LCAs.
- The availability of data is not sufficient and the quality varies widely. Data bases contain mainly mean values, for instance values for the whole of Europe. A lot of work is being done and soon improved data will be available to a greater number of users.
- LCA always involves simplifications and, because not all the required data are available, some information will unavoidably be of a qualitative nature.

8.3.1 Goal and Scope Definition

The goal and scope of the study must be clearly defined at the beginning. In this case the goal must be related to the precise objectives of the product development process. Usually designers need to know:

- What are the most important environmental problems of a product?
  And/or:
- What is the best design alternative?

However, the need for a qualitative LCA study (also referred to as a 'dirty') or a more quantitative (also referred to as a 'full') LCA study must be specified in accordance with the intended application.

The scope of the study should define the following items:

1. Function of the system, for example, considering a vacuum cleaner, the function of the system could be to provide a certain degree of cleaning.
2. Functional unit, which means a measure of the functional output of the system being studied that will allow the comparability of LCA data for alternative materials or products, for example, for the same vacuum cleaner, considering the degree of cleaning or the area to be cleaned in a given period of time.
3. System to be studied: the life cycle of the product should be considered, including all the stakeholders involved from raw materials extraction to final disposal. Depending on the system and on the goals, simplifications can always be made.
4. System boundaries: it must be determined which operations, inputs and outputs will be included in the study.
5. Extent and type of impact assessment to be used, if any, for example aggregation factors concerning global environmental problems, such as the greenhouse effect, and some local problems, such as pollution of a particularly sensitive area.
6. Data requirements, for example, only European data bases.
7. Assumptions.
8. Limitations.
9. Initial data quality requirements, including the variability and uncertainty of the information.
10. Type of critical review, if necessary, for example internal review, expert review or review by interested parties.
11. Type and format of the report required for the study, for example a spreadsheet to be presented to the company's product director.

8.3.2 Life Cycle Inventory Analysis

The life cycle inventory analysis is a process of data acquisition, quantifying materials, energy needs, liquid and gaseous emissions, solid and other waste during the entire life cycle of the product. Data are organized and managed in a data base. It includes process flowcharts, data collection and data processing. These data provide the basis for the life cycle impact assessment.

Inventory analysis is a physical description of the system, which means, according to ISO 14041, "a quantitative description of the material and energy flows across the system's boundary either into (inputs) or out of

(outputs) the system" (Fig. 8.3). The product system is the collection of operations which perform the defined function. The system's boundary separates the system from its surroundings, which acts as the source of all inputs and the recipient of all outputs.

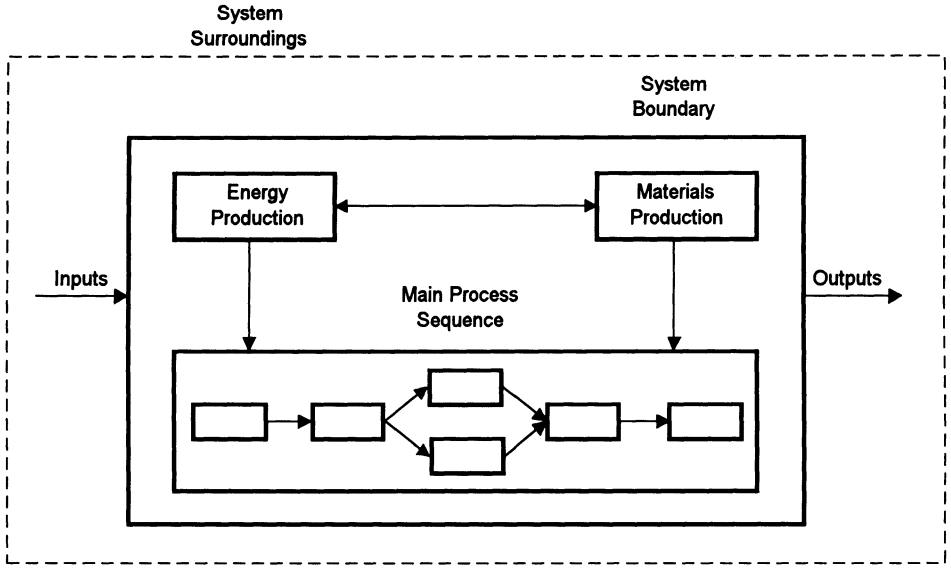


Fig. 8.3. A conceptual example of a product system for LCA. (ISO 14041)

To facilitate the identification of the inputs and outputs of the product system, it should be divided into unit processes, the boundaries of which are determined by the level of detail that is necessary to satisfy the goals and, in some cases, by the availability of data.

The information utilized to quantify the inputs and outputs of a unit process, may be categorized as shown in Fig. 8.4 (p. 123). The individual data categories will be more or less detailed depending on the goals under these headings, for example, carbon dioxide and sulphur oxides for emissions to air, organic matter and nutrients for emissions to water.

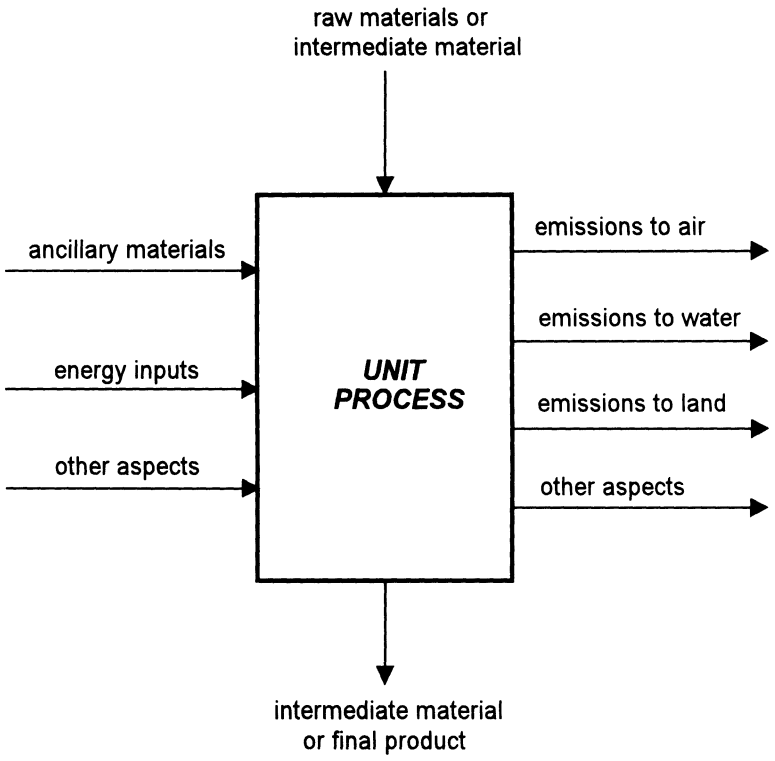


Fig. 8.4. Conceptual example of a unit process within a product system. (ISO 14041)

Common sense and advice from experts are important aids in performing a reasonable analysis. However, if the product concerned is too complex, software and data bases can be used, although this must be done carefully. A number of LCA software packages have recently become available to make an analysis easier, in particular the task of working through alternative scenarios.

8.3.3 Life Cycle Impact Assessment

Life cycle impact assessment is a mainly quantitative process for the characterization and determination of all flows and interrelations identified in the life cycle inventory analysis. The process aggregates the information concerning a group of global environmental problems, usually: resource depletion, energy consumption, global warming, ozone depletion, human toxicity, ecotoxicity, photochemical oxidant formation, acidification and eutrophication.

The level of detail, choice of impacts evaluated and methodologies used will depend on the goal and scope of the study.

8.3.4 Interpretation of Results

Finally, the findings are assessed according to the previously defined goal and scope. They then may take the form of recommendations to decision-makers.

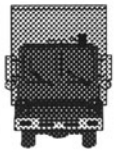
TV / PC

Example: What are the most important environmental problems of a product?

- What do we need for the manufacture of a personal computer? An LCA performed for a personal computer showed that companies in Europe and in the USA buy aluminium, oil, copper, tin, silver, cobalt and other materials from all over the world. The extraction and transport of all these raw materials require an amount of primary energy of around 5000 MJ per PC. The production of the computer itself will require an amount of primary energy of 32500 MJ per PC.
- The study showed, roughly, that the main environmental problems are related to the energy consumption during the extraction and transport of raw materials and the production phase (Fig. 8.5, p. 129) as well as to some emissions in these phases. The results also showed that the energy consumption during the use of the PC is not as significant as the amount of energy consumed during its production.

Example: What is the best design alternative?

- The Loewe pilot project for a disposal-friendly colour TV is presented in Chapter 10. The prototype was designed to be an almost single-material product: with the exception of the tube, all parts are recyclable as scrap steel. Considering the goals, one question arose: what was the best casing alternative for the new model?
- The casing is made entirely out of sheet steel. Some simplified LCA results for a PC are presented in Fig. 8.5. The results of the LCA for steel and for three different alternatives (another metal and two plastics) in terms of energy consumption and waste generation along the life cycle of the TV, are presented in Fig. 8.6 (p. 130). Besides the favourable energy and waste balance compared to alternative materials, steel has other advantages, such as the established recycling market, less need for harmful substances, increase in durability, protection against dust and easier disassembly. For further information on this case see Chap. 10.



Extraction and transport of raw materials

Prim. energy	5000 MJ
Energy cons.	2325 kWh
Emissions	
NOx	3.0 kg
SO_2	3.0 kg
CO_2	1400 kg
Waste	250 kg

Production

Prim. Energy	32500 MJ
Energy cons.	3010 kWh
Emissions	
Nox	1.25 kg
SO_2	2.14 kg
CO_2	1850 kg
Waste	60 kg

Use (1 year)

Prim. energy	2900 MJ
Energy cons.	500 kWh
Emissions	
NOx	0.20 kg
SO_2	0.35 kg
CO_2	300 kg
Waste	-

Recycling

Prim. Energy	160 MJ
Energy cons.	15 kWh
Emissions	
Nox	0.05 kg
SO_2	0.01 kg
CO_2	4 kg
Waste	2 kg

Fig. 8.5. Simplified results from an LCA of a personal computer. The amounts relate to 1 PC. (Grote 1994)

The results of the LCA for steel and for three different alternatives (another metal and two plastics) in terms of energy consumption and waste generation during the life cycle of the TV are presented in Fig. 8.6.

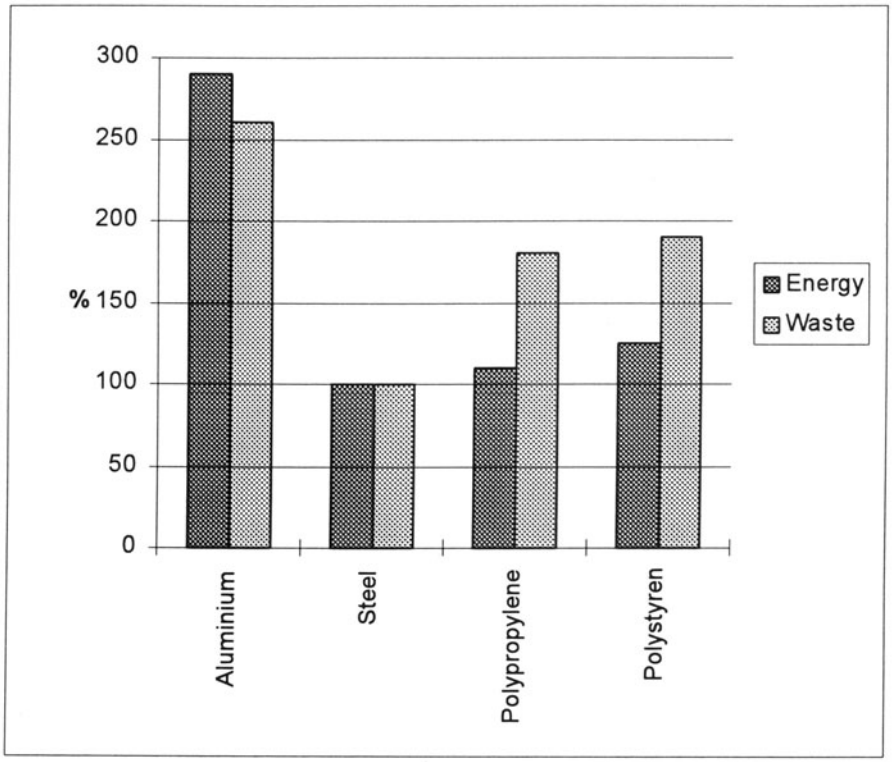


Fig. 8.6. Amount of waste and energy consumption for 3 TV casings (steel = 100 %)

8.4 Product Summary Matrix

Matrix approaches to abridge LCAs are based on the fact that when performing an LCA for a complex product, the results obtained will be useful only if they are semiquantitative and if modest depth is taken in conducting the study. This matrix method does not require a detailed life cycle inventory and further impact analysis and is easier to relate to the results of the inventory phase. Apart from these reasons, full LCA studies are still very time consuming and expensive, because the quantitative information requires a lot of accurate measurements and detailed reviews. To overcome these problems and simultaneously work on an improvement analysis for decision-makers is a difficult task.

Rapid LCA

The environmentally responsible product assessment matrix is an alternative method presented by AT&T for replacing full, comprehensive and time consuming LCAs. The goal is to do the LCA rapidly — in about two days for a typical facility — while identifying the principal environmental effects during the life cycle of the option evaluated (Graedel 1995). This method is purposely qualitative and utilitarian, as it results in a value that represents the environmental burden of the system or the product which is analyzed. The assessment is made by using a

5 x 5-column matrix, in which the life cycle stages are arranged in the matrix columns and the environmental concern in the matrix rows (Table 8.1, Graedel 1995).

Table 8.1. Environmentally responsible product assessment matrix.

Life cycle stage	**Environmental concerns**				
	Materials choice	Energy use	Solid waste	Liquid waste	Gaseous emissions
Premanufacturing					
Product manufacturing					
Product packaging and transport					
Product use					
Refurbishment-recycling-disposal					

The proposed assessment system follows some important principles such as enabling direct comparisons among rated products; it is useful and consistent for different assessment teams and it encompasses all stages of the product life cycle as well as all environmental concerns.

To each of the matrix elements one integer number is assigned representing the impact on the environment, ranging from 0 (highest impact) to 4 (lowest impact). Once the evaluation has been made for each matrix element, the overall environmentally responsible product rating (R_{ERP}) is computed as the sum of the matrix element values (Graedel 1995):

$$R_{ERP} = \Sigma_i \Sigma_j M_{ij}.$$

Because there are 25 matrix elements, the best possible product rating is 100.

Example: 1950s automobiles vs 1990s automobiles. Environmentally responsible product assessments of generic automobiles show that, in comparison to the 1990s models, the 1950s vehicles were heavier, less fuel efficient, prone to dissipation of fluids and exhaust pollutants and had less durable components (Tables 8.2 and 8.3). The rating of automobiles increased from 46 (in the 1950s) to 68 (in the 1990s).

Table 8.2. RERP Matrix for 1950's generic automobiles. (Graedel 1995)

Life cycle stage	Environmental concerns				
	Materials choice	Energy use	Solid waste	Liquid waste	Gaseous emissions
Premanufacturing	2	2	3	3	2
Product manufacturing	0	1	2	2	1
Product packaging and transport	3	2	3	4	2
Product use	1	0	1	1	0
Refurbishment-recycling-disposal	3	2	2	3	1
				Total	**46**

Table 8.3. RERP Matrix for 1990's generic automobiles. (Graedel 1995)

Life cycle stage	Environmental concerns				
	Materials choice	Energy use	Solid waste	Liquid waste	Gaseous emissions
Premanufacturing	3	3	3	3	3
Product manufacturing	3	2	3	3	3
Product packaging and transport	3	3	3	4	3
Product use	1	2	2	3	2
Refurbishment-recycling-disposal	3	2	3	3	2
				Total	**68**

9 Does Life Cycle Design Pay?

Aside from all the other challenges, the financial potential of a product is a central consideration. One rule says: an engineer's idea is worthless as long as the costs are not considered. This leads to the core question: Does ecodesign pay? There is no simple yes or no to this question, but there are some arguments as to why ecodesign will become an economic factor that cannot be ignored.

Before dealing with costs, it is necessary to define what kind of expenses need to be considered. There are the traditional economic costs of production and the aggregated costs of a product. In addition, there are hidden environmental expenses of production and of products during their life cycle. These hidden expenses at the production level are part of the general costs. At the product level the hidden costs are the price society pays for emission treatment, increased illness, cleanup etc.

Three levels need to be distinguished:

1. The national level, which encompasses all costs to society caused by the deterioration of the quality of the environment. Those often hidden, external costs are dealt with via new instruments such as ecotaxes, which try to integrate them into the organization's financial system. Thus a price is attached to the consumption of natural resources such as air, water and raw materials, which are no longer free of charge. — National level
2. The product life cycle level, which encompasses all economic and environmental costs of a product during its entire life cycle. The evaluation of the environmental impact at this level is done through product life cycle assessments, as standardized on a worldwide level within the ISO 14000 series. — Product life cycle level
3. The production level, which encompasses the economic and environmental costs of production at site. Organizations often have a very limited knowledge of their actual environmental costs. Improved knowledge will stimulate pollution prevention, as many cleaner technologies - once implemented - actually help to save money as well as resources. — Production level

To illustrate this, the car can be taken as an example. Up to now, society has paid for roads and borne the costs of emissions and other environmental effects. Via ecotaxes on petrol, part of these costs, as well as the costs of recycling and disposal, are shifted back to the consumer and the producer. The economic costs of the product during its life cycle include

e.g. petrol and maintenance costs. The costs of production are quite easy to assess. But the environmental costs of production not only include the disposal of waste from the production site but also the costs of air treatment, pollution prevention and waste management.

9.1 Product Life Cycle Costs

The term product life cycle has an economic and an environmental definition. If the environmental definition is followed, consideration will be given to:

- Raw material extraction.
- Production stages.
- Trade and distribution.
- Use.
- Disposal and recycling.
- Transport at and between all those stages.

Economic life cycle

The economic life cycle of a product begins with the first product idea and its design, covers the initial, peak and declining sales turnover and finally involves the stage where the product is taken from the market.

In order to distinguish the costs and benefits of life cycle design, the following steps will be discussed:

- Design costs.
- Environmental costs of production.
- Product pricing and marketing aspects.
- Product use.
- End-of-life costs.

9.2 What Are Design Costs?

The design of environmentally sound products is a complex task which requires extra knowledge and information on the environmental profile of natural resources, materials, processes, products and services.

Typically, design costs cover research and development as well as the testing phase of the product.

Yet another consideration is the quality of labour. Often, with the introduction of ecodesign, creativity and motivation of employees increase substantially as does management commitment. Thus, cost savings can be achieved in quality control, reduction of absenteeism etc.

Another important aspect for the designer is that, although some environmentally sound materials can be more expensive, their application can often save waste-treatment costs. It should also be calculated that products resulting from ecodesign will have a longer life cycle and their disposal will involve fewer costs.

Good examples prove that there is not always a trade-off between economic and environmental goals. The traditional conflict between production and recycling costs can be overcome by creativity and innovation.

9.3 What Are Environmental Costs of Production?

At first, waste disposal costs come to mind. But waste has a double meaning. Waste originates from raw material, for which the firm has paid but which has not been turned into a marketable product. Waste therefore is a sign of inefficient production.

The principle of pollution prevention not only leads to the question of how to dispose of waste, but goes beyond that: what was the source and how can production waste be prevented?

Pollution prevention can be achieved by changes in product-design or in the production processes, which are often linked to each other. Measures related to the production process include good housekeeping, selection of alternative raw and auxiliary materials and the installation and integration of cleaner technologies.

Environmental costs of production encompass:

- Waste-disposal fees.
- Waste-collection equipment.
- Waste-treatment costs at site.
- Staff hours for waste handling.
- Staff hours for waste production.
- Depreciation of facilities for waste and emission treatment.
- Storage costs for materials resulting from waste treatment.
- Auxiliary materials for emission treatment.
- Raw material prices reflected in the generation of waste.

Measures for pollution prevention can help to reduce disposal and emission treatment costs and contribute to increased efficiency in the use of purchased materials. The Prepare Toolkit lists the following savings potentials (Dimitroff-Regatschnig 1995):

- Cost reduction in waste treatment and disposal. This includes internal and external treatment-storage and landfill costs, fees for disposal, transport, insurance and liability, site and production permits and

reports to authorities.
- Savings in raw and auxiliary materials. Alternatives which reduce the amount of waste in general also need less material input.
- Savings in insurance and liability costs. Reduced generation of waste and emissions often lead to reduced risks of damage of such as spills, contamination of land, cleanup obligations or other related costs.
- Savings because of better product quality. Alternative product-design can improve product quality and thereby decrease the need for internal control or for redoing work. And it can lower the production of scrapmetal.
- Maintenance. Labour hours and material required for maintenance can also be affected by product-design.
- Earnings from new by-products. If waste is no longer produced but new, marketable by-products are made instead, the cost of new product-design can be offset by earnings involved.

Often, new product-design is prohibited by the existing machinery and tools, which are still functional. Investment in new equipment will only be considered once old equipment has been fully depreciated. However, often a new design can help to save money in other cost areas: therefore, careful calculation of the cost trade-off is necessary.

Eurostar

Eurostar, an Austrian car assembly plant, participated in a project called 'Ökoprofit' and achieved substantial cost savings by taking the following measures (Ökoprofit 1992):

- Replacement of grinding wheels. The result e.g., 2 tons less residual waste; the purchase of grinding wheels was reduced by 180000 pieces.
- Optimized measuring in the enamelling process (switch-on and switch-off points of the automatic spraying machines; division of the car body-surface zones).The result e.g., 10,5% less paint required.
- Change of filters in the paint-mixing plant: the paint from the filter is added to the new paint. The result e.g., 5000 l less hazardous waste; 5000 l less enamel.
- Prevention of drag out in the pretreatment of car bodies due to the installation of guiding plates and spray rings. The result e.g., reduction of waste by 30%; reduction of the proportion of solid material after precipitation by 50%.
- Drying of sludge from waste-water handling for reuse of waste material. The result e.g., 40% less sludge, eightfold volume reduction; reduction of paper transports from 12 to an average of 1.5 per day.
- Separation of waste for reuse of waste material. The result e.g., a recycling proportion of 95%.
- One of the future perspectives of Eurostar is to change to water-enamel technology for paint finishes (e.g. 30% reduction of solvent emissions per car).

9.4 Product Pricing and Marketing Aspects

Selling opportunities are among the main reasons for launching new products. But marketing also severely influences product costs. Often, when designers have a good idea, the marketing department argues that the customer will not like it. Therefore, marketing must participate in the process of building environmental awareness within the organization and among consumers.

Often, environmentally improved products have a higher selling price that is outbalanced by their longer life span. This needs to be communicated to the customers. But if we make these products cheaper, would anybody want the traditional range?

Marketing experts also often have serious concerns about the existing product range if they take a green product. Does this mean that all other products are bad?

Therefore, organizations which commit themselves to pollution prevention generally change their production processes and design guidelines. Eventually, the whole range of production will have an improved environmental performance.

Active inclusion of environmental aspects in the product-design and manufacturing processes helps to find new strategies and thereby leads to economic advantages.

With an environmental policy and an environmental management system, it is likely that an organization will obtain a positive company image which is associated with profiles such as being creative, innovative, flexible, future-oriented, social and responsible.

Ecolabels and environmental assessments by consumer organizations have aroused increased interest and have put pressure on producers and designers.

For many organizations, the environment is increasingly becoming a strategic production factor through which they gain entrance into new markets. One of the most impressive examples is the former east german freezer company Scharfenstein. At the point of closure, which would have left 600 people without work, the company was encouraged by Greenpeace to produce the world's first freezers using neither CFCs nor FCs for the cooling and foaming of insulation materials. With the help of a Greenpeace campaign, 70000 orders were placed before the first freezer even left the assembly line. Today, other producers offer CFC-free refrigerators, too.

9.5 Product Use by the Consumer

The Fraunhofer Institute for Manufacturing, Engineering and Automation (IRA) in Stuttgart, Germany, developed a figure which shows that future demands on technical products will be more and more related to the product use and disposal phase, whereas in the past the manufacturing process was used to be of core interest (Fig. 9.1).

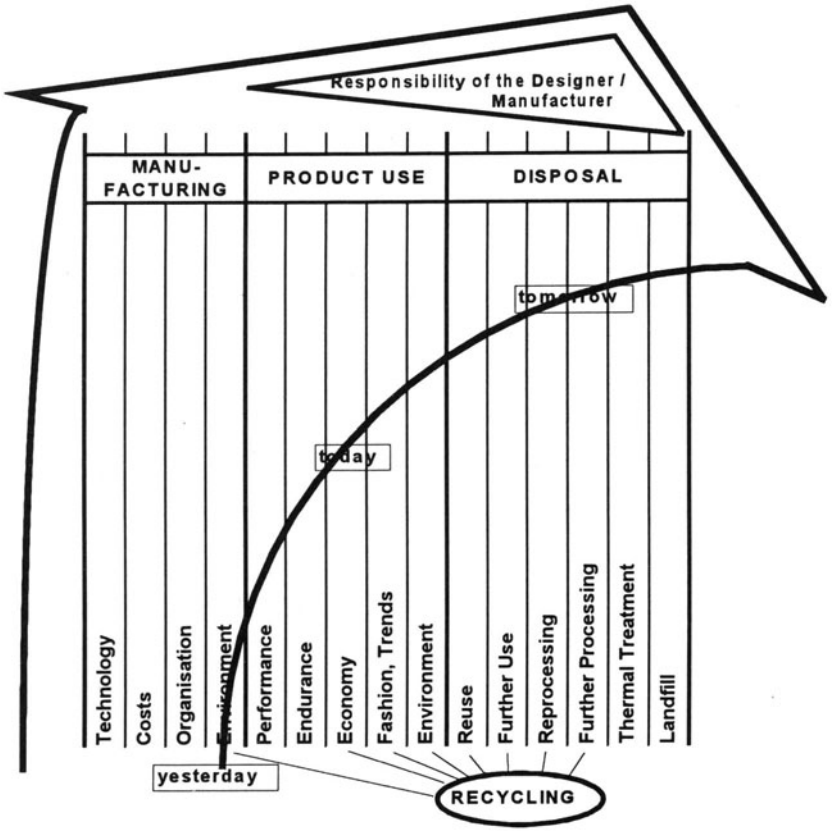


Fig. 9.1. Future demands on technical products. (Steinhilper 1996)

The cost shares of production, use and disposal tend to shift with the complexity of the product. As Fig. 9.2 (p. 139) shows, the share of maintenance and disposal costs in total production costs is rising significantly.

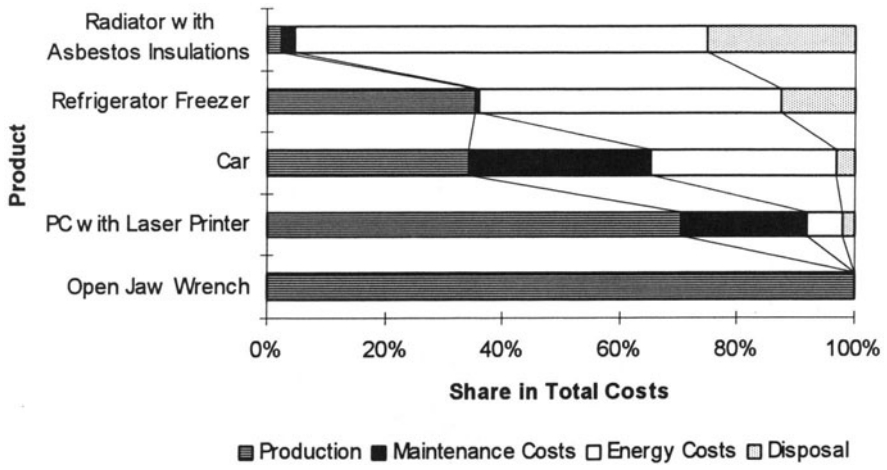


Fig. 9.2. Cost shares of production, use and disposal in the total costs of the product

In any case, less energy or water consumption in the use phase is not the only argument for buying a new product. The consumer must also consider the environmental impact of the production of a new product compared to an older one that ist still functional. For a refrigerator, for example, the energy input, including production, transport and packaging, is as high as 5300 MJ, which is equivalent to 1473 kWh of energy carriers. Estimating that producing 1 kWh electricity requires 3 kWh energy carriers, this leads to a total of 491 kWh electricity for the production of a refrigerator. If we assume that the new refrigerator will save about 0.30 kWh electricity per day, then it must be in use for 1637.11 days or 4.5 years to make up for the energy need of production.

Example: The costs of a boiler.
To improve energy efficiency in the domestic sector, many innovations have been developed in recent years. One of these innovations is the substitution of conventional boilers by condensing boilers. This innovation has considerably influenced costs for the different purchasers. The purchase costs of highly efficient condensing boilers are about 500 ECU higher compared to conventional boilers. On the other hand the installation of condensing boilers saves residents an average of about 400 m^3 gas per year. In the Netherlands this corresponds to savings of about 100 ECU per year.

9.6 End-of-Life Costs

Our current way of production and consumption treats nature as an unlimited source of materials having an unlimited waste storage potential. However, the resilience of land, water and air to extraction and pollution is limited and in some areas the limit might already have been surpassed. Our economy is accepting only gradually the idea of extended responsibility after sales.

Electric products

In 1992 electric and electronic products had a 2 - 3 % share of the total European production of solid waste, which means 4 - 6 million tons. For 1998 the estimate is 7 million tons per year or 50 million products. The costs of their treatment and disposal are likely to be shifted back to the consumer and producer. It is hard to estimate the future costs of take-back logistics, recycling technologies, hazardous materials and disposal. Nevertheless, some clear trends are noticeable.

Nearing the end of its life, a product can either be reused, recycled or disposed of.

Within the group electric and electronic products, huge differences exist in take-back logistics, materials used, functionality, life cycle, technical evolution etc. The aim of production and end-of-life optimization activities should be to establish and maintain closed cycles.

End-of-life processing of consumer electronic products has been split into 5 phases by Cramer and Stevels of the Netherlands. They are:

- Collection and transport
- Disassembly
- Mechanical processing
- Processing including recycling and final disposal
- Final Disposal.

Collection and Transport: From the final user to disassembly and recycling companies, the costs will depend on how the collection system has been set up logistically and who is going to collect and transport the consumer electronics products. These may be the retailers, local authorities and/or industry, possibly through a separate organization.

Take-back systems

Take-back systems must be organized carefully with regard to the air pollution caused by long-distance transport. Two basic models exist: a model in which several regional collectors take care of different types of equipment from all producers or a model in which a few collectors specialize in equipment of one type (e.g. TV sets) or from one producer only. The few existing collection systems mostly are of the first category and are organized by municipalities. The costs for product collection can hardly be influenced by the designer and have been estimated to be about

one-third of the total end-of-life costs.

Disassembly: The disassembly costs depend on the time required to disassemble the product and whether this must be done manually or technically.

A good example of savings achieved through better disassembly is the completely new construction method for electronic products from Hewlett Packard.

The structural components and printed circuit boards in the computer shell are not screwed or otherwise put together, but are embedded in foamed frames and are held in place without any need for further fastening. The need for rivets, binders and other fasteners has been eliminated completely.

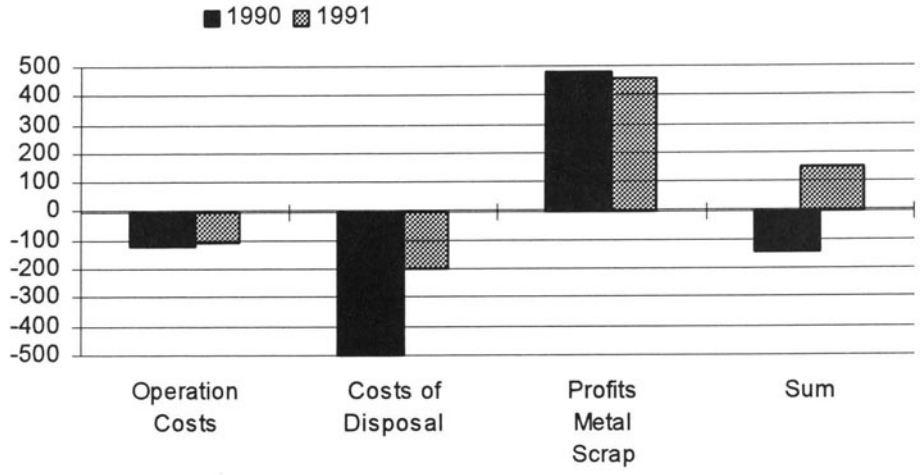
Disassembly consists only of opening and turning the computer ('opening a drawer'-product-design according to the principle of a cutlery box). All components will then simply drop out and there is no need to loosen any screws and fasteners.

The advantage of this new product is that the time needed for disassembly is sharply decreased (see Chap. 10).

Mechanical Processing: The costs of mechanical processing arise through the application of shredders and other separation techniques. Mechanical processing is much less expensive then manual disassembly, but makes it more difficult to obtain pure and therefore more valuable materials. On the other hand, Eversheim has used the example of a family car to show that in the future manual disassembly might be more economical than shredding as the separated material fractions can be completely recycled and there would be no disposal costs.

Balance Shreddering

	operation costs	costs of disposal	profit metal scrap	Sum
1990	-120	-500	480	-140
1991	-110	-200	460	150



Balance Detachment

	operation costs	profit metal scap	profits catalyst	profit plastic	Sum
1990	-850	-410	40	220	-140
1991	-850	-400	60	130	150

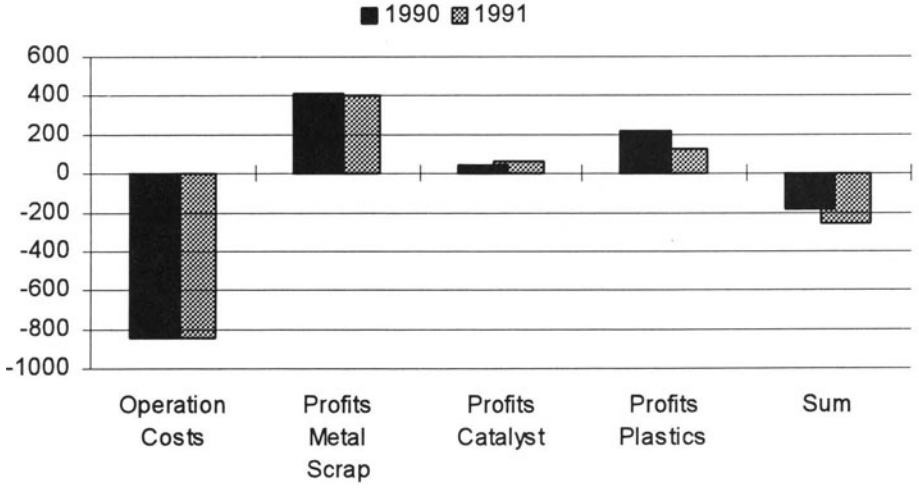


Fig. 9.3. Balance shredding and detachment according to Ewersheim. (Möller 1984)

An example from the US: not only car parts, but also huge and unwieldy machines such as vending machines or full-fledged industrial robots are transported over the disassembly and reassembly belts. In this case it is above all a multitude of medium-sized enterprises that have discovered this market niche and are trying to fill it. An enterprise with 130 employees, for example, refurbishes beverage can vending machines that have been in use for 10 years. About 150 such machines are modernized down to the last screw and reassembled in this factory every week.

Processing Including Recycling: Benefits can be gained through processing if the value of the separated materials is high enough. For instance, plastic regranulation, glass reuse and copper smelting are suitable for further processing. The material distribution in electronic waste for the year 1998 has been estimated by an EC working group (EC-Arbeitsgruppe 1994) on major electronic waste (Table 9.1).

Table 9.1. Material distribution in electronic waste in 1998 (%)

Category	FE metals	NE metals	Glass	Plastic	Other
Data processing equipment	35.0	19.0	19.0	22.0	5.0
Office equipment	62.3	26.7	0.3	10.0	0.7
Telecommunication	28.0	15.0	0.0	55.0	2.0
Video + sound machines	20.0	6.0	30.0	25.0	19.0
Household	52.8	5.9	2.4	18.6	20.3
Equipment for hotels, restaurants	77.0	5.7	1.6	9.9	5.8
Cables	4.0	53.0	0.0	38.0	5.0
Lamps	4.5	5.9	86.4	1.4	1.8

Final Disposal: The costs of final disposal depend on the amount and type of waste.

Considering the shortage of landfill capacities as well as the fundamental problems with solid waste incineration and hazardous waste treatment, disposal costs can be expected to rise significantly.

In 1988 the German city of Nuremberg bore disposal costs for shredded household equipment, cars etc. of 14.5 DM per ton. In 1991 the disposal of one ton cost 350 DM. In the same period the costs of incineration rose from 75 DM to 483 DM per ton, the costs of the disposal of hazardous waste rose from 120 DM to 350 DM per ton.

This development applies not only to waste from production processes but also to disposed products. It can be expected that producers will

eventually be obliged by law to take their old products back.

Customers and politicians are also becoming more and more interested in products that are taken back and disposed of by the producer. Environment and recycling-friendly production processes and products are thus becoming a significant marketing factor.

In 1994 the European Commission launched the 'Priority Waste Stream Programme for Electrical and Electronic Equipment' as a basis for a EU directive. It is estimated that in the EU there will be 7 million tons of electronic waste in 1998. At the moment most of it is sent to landfills and incinerators, where the hazardous materials cause problems and much valuable material is lost.

Taxes on the use and disposal of specific products are already in effect in some European countries. Their share of the national income is likely to increase. These taxes work in two ways: on the one hand, they make the environmentally harmful product more expensive, which results in a decreased demand. On the other hand, the money earned can be spent on prevention, cleaning and protection measures.

Product liability

In the near future, organizations will become responsible for the end-of-life stage of their products. In some industries, e.g. for packaging waste, this is already the case, and electronic waste will soon follow. This product liability will include:

- Take-back obligations for used products.
- Installation of disassembly, recycling and processing facilities.
- Reuse of components and materials.
- Burden of proof for environmentally sound disposal.

Liability for possible environmental damage resulting from products is also increasing, due to European environmetal laws.

10. Environmentally Innovative Cases

During the past 20 years, a new global awareness has grown that provides the basis for the shift to sustainable production and consumption patterns (Schmidheiny 1992).

In this context the demand for 'green' products has emerged and the attention of governments and consumers has been directed towards the minimization of the environmental impact of products during their life cycle. A new dimension has been added to the attitude towards products. Designers no longer think only of the conception of the product itself. The design discipline has became broader and a product is now considered to be a complex interrelation in the form of a life cycle along which materials and energy flow.

Whereas companies are improving their environmental performance and achieving outstanding results with resource conservation and pollution prevention, the emphasis has shifted from the production process itself to environmental concerns related to the products that result from these production processes.

Considering the pattern of rising mass production, a very important goal is to promote sustainable industrial development, based on a balanced use of raw materials and energy and the minimization of waste and pollution resulting from industrial production processes in order to achieve ecoefficient processes.

Ecoefficiency

Ecoefficiency cannot be achieved by technological change and process modifications alone. Profound changes are required in the goals and assumptions that drive corporate activities as well as in the daily practices and tools that are used (Schmidheiny 1992).

Various cumulative pressures, coming from several directions, have forced many companies to go back to their drawing boards to design products which comply with the ecoefficiency practice, i.e. which pollute less and consume fewer resources. Examples of those pressures are: environmental regulations for waste disposal and emissions; increasing environmental awareness of consumers; environmental product labels; and obligations for companies to take-back used products. What originally could be described as a threat to companies turned out to be an opportunity for innovation and competitiveness, that guided companies that adopted ecoefficiency rules to a stronger position in the market.

The increasing complexity and international nature of product sourcing

implies that companies that want to act in a responsible fashion must adopt a global approach to product stewardship (Schmidheiny 1992).

This chapter focuses on eight products that resulted from ecodesign, produced by different companies, to highlight the work underlying the development and implementation of environmental criteria. In the description of the product examples, all references to names of companies are presented exclusively to illustrate the path taken towards the ecoefficiency of products.

Improvement alternatives

The following cases are presented to motivate the search for alternative improvements and to avoid the use of conventional wisdom that might marginalize environmental concerns. They do not represent a paradigm but rather provide useful guidelines and pose new challenges for product improvement. In many instances, emerging conflicts between different environmental criteria are well-known and the need to go beyond mere improvement will be addressed.

10.1 The Disposal-Friendly Television Set from Loewe Opta GmbH

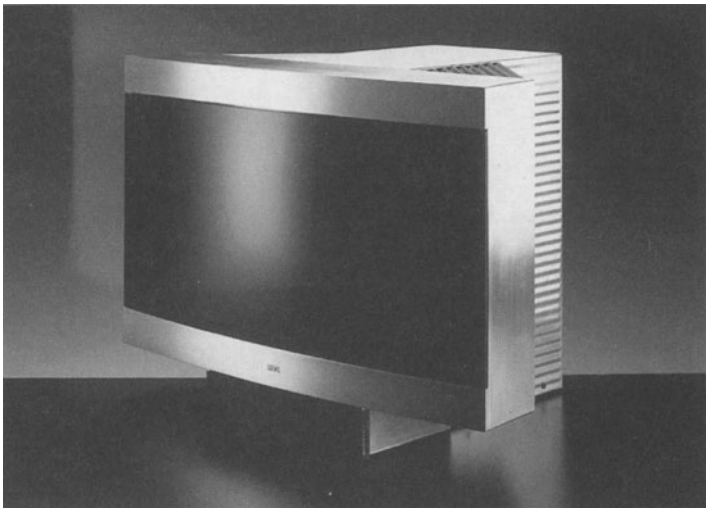


Fig. 10.1. Prototype steel television set by Loewe Opta GmbH. (Loewe Opta GmbH)

10.1.1 Introduction

In a pilot project, the German company Loewe Opta GmbH, based in Kronach, developed a disposal-friendly colour television set which was first presented to the public at the International Exhibition of Consumer Electronics (Internationale Funkausstellung) in Berlin in 1993.

Realizing that the technology used in the home electronics industry has considerable potential environmental impact, the company decided to take new paths.

Problem: thermosetting printed circuit boards

Thermosetting printed circuit boards, for example, were replaced. As this inflammable material is used in areas of high performance, it is essential to prevent a fire in the appliance in the case of malfunction. This is generally achieved by using highly toxic additives. The use of thermosetting materials in these areas is therefore highly unsuitable. Alternative materials that comply much better with the technical requirements were therefore considered. As a result, for the prototype, electric circuits on a ceramic-based substratum were used in combination with a steel casing.

Problem: complex structure

At present, it still does not make economic sense to disassemble complex products, such as television sets, which consist of more than 2500 components. Therefore, the prototype was designed to follow the principle of single-material usage. With the exception of the tube, all parts are recyclable as scrap steel. The objective was to make the electronic elements from materials free of harmful substances and compatible with

one another, such as iron, aluminium, silicon and their oxides, and to apply as few halogen-containing hydrocarbons as possible.

10.1.2 Essential Product Innovation

The essential ecological features of the prototype are the materials used for the casing and the electronics. The casing is made entirely out of sheet steel. Flame retardants have thus become unnecessary. Furthermore, the use of steel as casing material offers the following advantages:

- Favourable energy and waste balance compared to plastics and aluminium.
- Established recycling market for scrap steel.
- Powder coating without solvents and heavy metals.
- Strict regulations such as MPR II are adhered to through optimal screening against electro-magnetic radiation and x-radiation.
- Increase in durability of the electronics through optimal canalization of waste heat without the conventional metal sheet cooling.
- Electronics protected against dust since cooling slits for ventilation are not required.
- Flame resistant, therefore no need for flame retardants.
- Easy separation for recycling by means of magnetic separation.
- Neutral effect on dumps and in incineration, in the case of uncontrolled disposal.
- Low cost for tools for small number of units.

Setup of electronics

The electronics have been changed to thick-film hybrid technology. A hybrid circuit combines components in the form of films that conduct electricity (conductors and resistors) as well as conventional components (capacitors, inductors and semiconductors) on a ceramic substratum. The ceramic material used is aluminium oxide (Al_2O_3, Rubalit) which in thick-film circuits has a purity of 96%. Through the use of this flame-resistant carrier, the use of flame retardants has been eliminated. With the thick film technology, films of > 1-2 µm thickness are applied to the ceramic substratum, whereby the typical values in component technology are 10-15 µm for conducting films and 30 µm or more for insulating films. The application of conducting and insulating films is carried out by means of screen printing.

Surface-mount-technology (SMT)

Another feature of the technology applied here is that the components are mounted directly on the substratum using the so-called surface-mount-technology instead of being soldered into drilling holes as is done with conventional circuits. The electronic components such as ceramic capacitors, wire-wrapped parts, small diodes, resistors and electrolytic condensers, were replaced by their SMT equivalents wherever possible. In

this way, materials can be saved, since many SMT parts are much smaller than their conventional counterparts because they do not require casing or lead wires.

10.1.3 Advantages of the New Concept

In all, the number of electronic components was reduced from 1075 to 943 items, the weight of the electronics being reduced from 2.13 kg to 1.33 kg. Plastic parts were reduced from 6.68 kg to 39 g and flame retardants were no longer required. In this way, materials containing harmful substances were reduced by a factor of 100. The following diagram shows the advantages of the new concept in comparison to a conventional television set (Fig. 10.2):

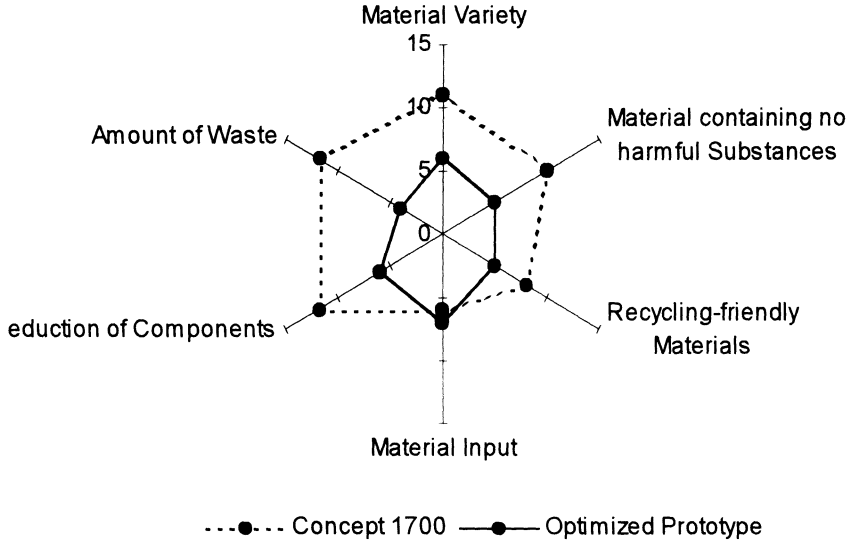


Fig. 10.2. Comparison of the Loewe Opta prototype and a conventional television set

Limitations in realization

The final objective of the concept was to free electronic parts from harmful substances and halogens so that they can be recycled or disposed of together with the scrap steel. This has not yet been fully realized with the prototype. One reason is the dependency of the manufacturers of televisions on manufacturers who deliver special components for large numbers of units only. Their market position is very strong. In the

production of semiconductor casing, for example, they have little interest in changing their processes. Another reason is the presently high cost of alternative technologies that are free from harmful substances (such as naked-chip or chip-on-board technology).

Therefore, there are still components in the electronic elements that contain flame retardants in their casings (film capacitors, semiconductors) and thus prevent recycling via scrap steel. Furthermore, the large wire-wrapping parts such as the high voltage and mains transformation contain copper, which is undesirable in the melting process of steel. Plans to replace copper, with aluminium (which is less precious than iron and can therefore be removed via the slag in the melt) have so far not been realized.

Base substratum

Further plans include replacing the ceramics by thin copper-coated foils in connection with carrier materials as a base substratum. This method is not yet ready for series production but involves less cost. This technology has a considerable innovate potential with improved environmental features that could lead to the replacement of the conventional thermosetting printed circuit boards in the near future.

Alternative casing material

With regard to the casing, further developments are possible. In this concept, it does not necessarily have to be made of steel. If the electronics are designed with sheet steel or another metal as a carrier material, there are easy ways to protect them electrically and thermally. For this reason, inflammable materials could also be used for the casing, provided that the design takes easy disassembly into account. As soon as the chemical industry has solved the recycling problems, plastics will become a suitable material for casings again.

Reduction of power consumption in stand-by mode

Energy Consumption: Apart from a reduction in the use of harmful substances and improvement of the disposal aspects, a reduction in energy consumption was a priority. The stand-by mode plays a big role in the total energy consumption of a television set. It was possible to reduce the power input from an original 15 to 1 W, by means of an intelligent circuit design. Furthermore, it is envisaged to use solar cells for the remote control.

New design qualities

Design: Although it was thought that steel would offer only limited design possibilities, it turned out that steel today actually presents a potential for new design qualities. Steel is regarded as a high-quality high-tech material by many customers, which in connection with a 'green' concept presents a positive change from the conventional television set that has a high percentage of plastics.

10.1.4 Outlook

Applicability to other product groups

As series production was intended, the pilot project showed that the results obtained are also of importance to product groups where similar problems exist. In the choice of materials it is particularly important to include environmental aspects for their respective areas of application.

It will be possible in the future to avoid electronic scrap on a large scale as well as chemical waste, which is a considerable cost factor. Valuable materials would not be lost but returned to the industrial material cycles.

10.2 The OCÉ 7050 Copier

Fig. 10.3. The Océ copier machine. (Océ, advertising brochure)

10.2.1 Introduction

Océ 7050: Large-format plain-paper copier

The Océ 7050, a large format plain-paper copier, is an example of an energy-efficient, nontoxic and reusable machine. The design was part of the development project for ecodesign tools with the help of the TNO Product Center. The copier is a Dutch example of good environmental performance and was introduced very successfully.

Designed for the environment

Dealing with safety and environmental issues is part of Océ's company policy. In the design, construction and application of machines, Océ puts a lot of emphasis on issues such as design for reuse and recycling, energy consumption, noise, dust, waste and ozone emission. Knowing that copiers cause specific environmental problems, Océ tries actively to find solutions.

Several environmental issues are related to office machines in general. Photoconductors in copiers are of special concern since they may contain cadmium sulfide or selenium. Toner waste can cause dust emissions from toner powder.

Since copiers are complex products, various components and materials are hard to identify and recycle. Some components, such as circuits

boards and cables, could still be used but are disposed of because other components are worn out. Another environmental problem is posed by the fact that not all copiers can operate with recycled paper.

Emissions such as ozone, dust and noise from copiers are further concerns. Ozone can cause unpleasant odours, irritation of the eyes or throat and coughing. Ozone emissions from copiers and other electrical appliances can occur as a result of electrostatic charging. Another established fact is that the noise generated by copiers with inadequate sound proofing is considered troublesome by many employees.

10.2.2 Essential Product Innovation

Lease concept

Most of the Océ copiers are leased instead of sold. This means that Océ pays the repair, maintenance and disposal costs. As Océ bears the responsibility over the entire life cycle, copiers are designed to be durable, easy to repair and reusable after refurbishment.

Lease copier

Most Océ copiers are reused two to three times. The importance of durability is evident because a durable copier can be used longer and exploited more cheaply. This example shows that the product requirements of a leased copier can at the same time be cost-effective and environmentally benign.

Low electricity use

The copier type 'Océ 7050' has a low electricity requirement. An explanation for this is the newly developed "instant copy" which sets the copier at the right temperature within a few seconds. With the instant-copy system and the low fixing temperature of the toner, the copier sets its temperature during paper transmission (printing process). Hence, the copier does not need to be preheated before a copy can be made. This saves waiting time for the user and energy consumption. The copier is in a standby-mode of only 9 W most of the time.

Low emissions during use

The Océ copier has low emissions of ozone, dust and noise. In most copiers, ozone is generated charging of the photoconductor, image transfer and resetting of the photoconductor. This copier only generates ozone during charging of the photoconductor. Ozone emissions are further reduced by an extremely effective filtering technique using a carbon-activated coal filter. The Océ copier has a closed toner system for replacement of the toner bottle. Only after the bottle has been screwed into position is the toner bottle turned upside down. This system prevents spoilage of toner. During normal use the copier also does not produce detectable particle emissions. For noise reduction, the Océ copier has a sound-proofing system that meets high standards.

Removal of harmful substances

Photoconductors in copiers normally can contain cadmium sulfide or selenium. The photoconductor in Océ copiers are free from these substances: they are made instead of polyester bands coated with zinc oxide. In the 7050, as in other recent products, organic photoconductors are applied. Residual toner can be returned to Océ for reuse and toner bottles consist of polyethylene.

Saving resources

Special attention has been paid to the use of recycled materials. Several plastic and aluminium parts contain high levels of recycled material, which helps close the material life cycle.

Durability

The drum used as photoconductor is also long-lived; for most customers replacement will not be necessary. In case it is, the drum can be reused.

Design for disassembly, reuse and recycling

The Océ copier is built for easy disassembly and recycling. When the copier reaches the end of its life, the steel frame is not disposed of but is refitted with a new copying engine and is ready for reuse. Components not subject to wear, such as cables and printed circuit boards, are also reused in new Océ copiers but only after undergoing the same rigid quality control tests as new components. Machine components that cannot be directly reused are sorted and recycled. This includes such materials as aluminium, brass, iron and synthetic materials. Recycled and standard paper can be used easily in the copier.

Packaging

The development of the copier has also resulted in a reduction of the use of packaging material.

10.2.3 Advantages of the New Concept

Total energy consumption has been reduced three to four times. Harmful substances such as selenium and cadmium in the photoconductor and hazardous substances in the toner habe been eliminated.

The emissions during use are below exposure limits:

- The measured ozone concentration is 0.004 mg/m^3 while the Occupational Exposure Limit (OEL) is 0.2 mg/m^3.
- The dust concentration does not exceed 0.25 mg/m^3 while the prescribed threshold limit is 10 mg/m3.
- The sound pressure level in dB(A) of the 'Océ 7050' does not exceed 40 dB(A) at stand-by and 65 dB(A) in operation. According to the VDI guideline 2058, the damage threshold is 80 dB(A).

Furthermore, the drum used as a photoconductor is durable. Parts such as the steel frame, cables and printed circuit board can be reused in new Océ machines and materials such as aluminium, brass, iron and synthetic materials are sorted and recycled. Finally, recycled paper can be easily used.

The "instant copy" system provides both energy reduction and conven-

ience because it is no longer necessary to wait for the copier to warm up. Due to the fast warming system, the copier will be in stand-by mode most of the time. During that time, no heat, noise or odours will be emitted. This allows the copier to be close to working areas. The closed toner system renders toner refilling easy and clean.

10.2.4 Outlook

Most of the improvements on the Océ 7050 can also be applied or have already been applied to other copiers. New copiers will increasingly be developed for easy installation of reused parts. The ecodesign tools that were developed under the Océ 7050 project will be applied for future developments.

10.3 The Greenpeace Clean-Tech Cycle

10.3.1 Introduction

Greenpeace Germany and Greenpeace Switzerland organized a project for the production of an environmentally friendly bicycle: 'The Greenpeace Clean Tech Cycle'. The bicycle was produced in 1990 in limited series and presented for the first time during the IFMA (International Bicycle and Motorcycle Fair) in Cologne.

Environmental approach

The environmental approach was centred around the aspect of quality. By selecting the two equipment suppliers Suntour and Shimano it was possible to work with manufacturers who, with regard to standards of quality, apply the latest technological developments. No cheap parts were used that wear down, thus saving resources and producing as little waste as possible. The quality factor was indeed the main challenge for Greenpeace in order to guarantee durability and reliability of the materials.

Two different models were produced featuring alternative equipment and presented by both of the equipment suppliers. They offer a 20-year guarantee against rust and a 5-year guarantee against breakage.

The ecodesign principles for 'The Greenpeace Clean Tech Cycle' were developed by devoting special attention to the following fundamental environmental problems:

Chlorine-based chemicals cause enormous environmental problems. Compounds such as CFCs, PCBs, PVC and chemicals for the bleaching of pulp are toxic and must be avoided during processing. Environmental improvements of the bicycle included the complete elimination of chlorine-based chemical products.

As enormous quantities of electricity are used to produce aluminium, one of the objectives was to refrain from applying this metal as much as possible. Yet other objectives were to eliminate chrome plating and zinc plating wherever possible. Metal surface treatment generally causes water pollution by toxic heavy metals. The severity of this impact depends on the pollutant concerned. Heavy metals can be toxic, carcinogenic and persistent.

10.3.2 Essential Product Innovation

Design improvements were realized after assessing all bicycle components and working towards changes both in the materials used and the processes applied.

Replacing aluminium for durability and environment-friendliness: The steel of the Greenpeace bicycle frame is alloyed with molybdenum and chromium for greater stability. Other materials such as aluminium, titanium and carbon fibres would clearly be less environmentally benign, as the parts are usually socked and soldered with soldering metal. This necessitates several cleaning stages, for which solvents are commonly used. Cr-Mo-steel has been chosen to improve the frame because it is the most environmentally friendly material available on the market today. Welded frames save sockets, welding metal, flux and at least one stage of cleaning.

Standard handlebars are made of aluminium or Cr-Mo-steel painted with a liquid containing solvent or chrome plated. Improvements include the use of chromoly steel handlebars that are more reliable against breakage than those made of aluminium. Furthermore, solvent-free powder-coated painting was chosen.

There are three types of standard racks on the market, that are made of different combinations of materials:

- Aluminium-steel-plastic racks with plastic parts that connect aluminium struts which, however, lack strength in the connection points.
- Aluminium-steel racks, in which zinc-plated, riveted steel pins hold the rack together, but in which the connection between the materials is also weak.
- Aluminium racks which are welded and sometimes painted with a liquid that contains a solvent or a Cro-Mo tube that is welded and powder coated.

The improvement consisted of a specifically manufactured product: the Cro-Mo rack, welded, soldered and powder coated. In this case the replacement of standard materials by an environmentally friendly material has the additional advantage of being able to support an up to 50 kg load.

Powder-coated paint work for durability and more environmentally friendliness: After being cleaned, usually with a solvent, the frame is normally painted with three coats. Here again, paints are used that contain solvents and on the inside, the frame is normally not protected against corrosion. In the painting process of the Greenpeace bike, no solvents are applied. The newly developed process involves painting with electrolytic and immersion techniques and then applying an electrostatic powder coating, which altogether is an eleven-stage process. In addition, 100% of the material is used, thus preventing waste. The air in the working area is so clean that it can be inhaled without causing health problems. The inside of the bicycle frame is also protected against corrosion. This sort of coating presents a markedly higher protection against scratching, knocks and rubbing.

Avoidance metal chrome-plating: The handlebar is made of steel, thus facilitating recycling. It is painted with a solvent containing paint rather than chrome plating. No galvanic plating process was used. The standard rear cassette is six- or seven-fold and exists in diverse types and teeth shapes, depending on the manufacturer. The sprockets are usually galvanically surface treated in order to achieve better protection against corrosion. The models considered involve different improvements presented by the two manufacturers. Model A improvements include a pinion that is only burnished, since protection against corrosion can also be achieved by using wax or by lubricating the chain. Model B presents a similar but hyperglide 28-fold sprocket, which is silver-treated. A standard zinc or chrome-plated 'inbus' screw was used. The existing screws were replaced by high-grade steel.

Avoidance of plastic materials: Standard hand grips are made of plastic, are foamed (CFC) and contain PVC. The new hand grips do not contain CFC or PVC. The pedals are composed of plastic and metallic parts. The metallic parts include burnished chromoly wheel shaft, cup-and-cone bearing, an aluminium frame and chrome-plated screws. Rubber-block pedals are usually made of PVC. An improvement here is the avoidance of PVC for the pedal block.

There are DIN standards for lighting systems on bicycles. The introduction of the front reflector has added yet another plastic part to bicycles. Improvement here consists of an integrated front reflector: the mount was painted by layered cataphoretic immersion and the casing was made of alkylbenzenesulfonates (recycled plastic), which renders it shock-proof.

Standard coat protectors are composed of plastic sheeting with an aluminium core, zinc-plated riveted fastenings with zinc-plated stays and screws. These parts are not recyclable and the materials used do not assure the required durability but rather increase the chance of breakage.

Improvement here is directed towards the entire replacement of the materials concerned by applying high-grade steel, all fastenings included. Powder coating is used instead of zinc-plated surface treatment.

Roller parts, especially designed for lubrication: The disadvantage of standard pedal bearings is the impossibility of relubricating them without complete disassembly. Deep groove ball bearings, which are very well sealed and mounted as a unit, continue to be the norm. In the event of a defect they must be replaced completely and cannot be recycled. The rear wheel hub presents the same problem; in the event of a defect, it must also be completely replaced.

Improvements concerning all the working parts are related to long life as an important quality to be achieved. Regular external maintenance of these parts leads to a four-fold increase in longevity. The wheel hubs are

designed for longer life as they can easily be lubricated.

Improvements in the construction of gears and dynamo: The current generation of dynamos consists of composite parts that are made of a great variety of materials. In the event of a defect the whole unit must be replaced. The improvement of the conventional rotary dynamo includes an easily replaceable friction wheel to avoid replacement of the whole unit in the case of malfunctioning. There are no cables connected to the casing, but a clamping mechanism.

10.3.3 Advantages of the New Concept

The main advantages of the new concept are increased efficiency, road-worthiness and safety. Some technical advantages arise from the use of special materials and design improvements for both models. This is presented below.

The new bicycle is designed to be highly road-worthy and safe so that it presents a real alternative to the car. Ergonomics and the renunciation of cut-price manufacturing were the criteria considered for the prototype. Long life and reliability are incorporated to save resources and prevent waste, thus eliminating disposable parts.

Disassembly into the smallest possible separate components was also considered in the design conception in order to increase reparability and recyclability.

The many transport routes associated needed to purchase the components increased the total amount of energy required to produce the bicycle. Greenpeace's idea was to minimize transport routes, but much work remains to be done in the area of transport optimization.

Technological advantages: This year, hubs and inside bearings that can be lubricated were presented in a production version of the high-quality 'Suntour' model. For that model, the qualitatively best and most durable parts currently available were selected.

The model also has self-reinforcing brakes that are normally used for tandems and the most expensive mountain bikes. This means an end to braking problems even when the bicycle is heavily loaded.

A gear unit coupled with a thumb switch is a newly conceived element from 'Suntour'. It is similar in construction to more expensive units and differs only in the surface finish. These parts were used in order to present the bike in an attractive price range.

In the 'Shimano' model, more emphasis was put upon tried-and-true elements. The pedal bearings and wheel hub are well sealed against dirt

and water by floating gaskets and washers. A gear-change construction has mountain-bike quality, but here too the surface treatment has been modified.

Hyperglide sprockets in the 'Shimano' model have the advantage that changing gear on hills or with loads is simple. Parts that otherwise are found only on touring bicycles have in part been redesigned and are of top quality coat protectors are of high-grade steel, as are fasteners and supports. No more problems with broken or crooked mudguards will therefore arise.

10.3.4 Outlook

Certain components need further improvement. Therefore, future development goals are still being considered, particularly in material selection. In order to increase the quality of the product, future developments with regard to environmental aspects are:

- Elimination of aluminium in the remaining metallic components (stand, chain guard, pedal unit and wheel rims).
- Elimination of plastics (chain guard, hand grips and bowed cables).
- Elimination of chrome-plating processes.
- Improvements in construction, including the avoidance of composite components in the gears and the dynamo and a hub gear change to replace the derailleur.
- Ecologistics as an important issue when the complete life cycle approach is adopted. Future developments must include transport-route optimization in manufacturing.

10.4 Hewlett Packard's Disassembly-Friendly Workstation

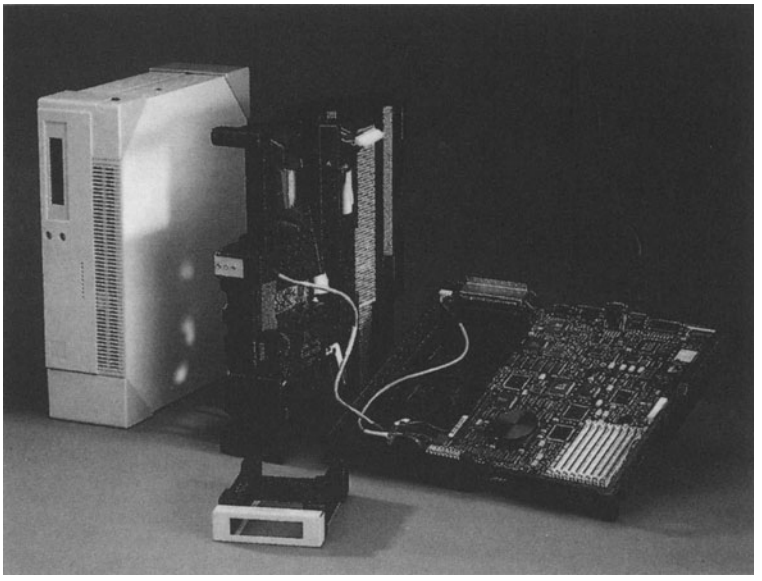


Fig. 10.4. Packaging assembly concept. (Hewlett Packard; Ruch Novaplast)

10.4.1 Introduction

The disassembly-friendly workstation developed by Hewlett-Packard complies ideally with all design requirements for easy disassembly. This product no longer presents a multitude of traditional connecting elements such as screws, clamps, rivets etc. In order to disassemble the appliance, the computer is simply opened and turned. The component groups then disconnect without the need to loosen a single screw or any other connecting element. There is no need for any tools in the disassembly process.

10.4.2 Essential Product Innovation

Packaging Assembly Concept: A completely new technical concept uses packaging materials for fixing the components. Instead of connecting component groups or printed circuit boards with screws or joints, the individual components such as the processor, disk drives or memory boards are held in place without any additional fixing. This is achieved by means of chassis parts made from expanded polypropylene foam, formed to suit the individual shape of the parts.

Fig. 10.4 shows the layout of the computer which resembles packaging, only here the components are placed inside. The lower part holds the components while the upper part ensures that they remain in place.

10.4.3 Advantages of the New Concept

Efficient air cooling

Saving material and energy

There are a number of advantages to this concept. Air-flow ducts ensure a well-directed and efficient air cooling of components and component groups. The use of foam instead of steel and injection moulding saves materials and energy, as the appliances are more compact and less heavy. Furthermore, the appliances are less noisy because the foam absorbs much of the noise of the ventilator and of vibrations and resonance.

The economic packaging assembly concept (EPAC) also shows that an environmentally friendly design can be particularly economic and competitive at the same time (see Chap. 9, section on costs). With this method, the appliances can be developed, manufactured, transported and at the end disassembled in a more cost-effective way. Compared to a conventional model, the HP workstation shows a 50% savings for the development of the casing mechanism, 50% savings in assembly time, 30% savings in transport packaging and 90% savings in dismounting time. The development of tools for mass production is cost-effective, too. Altogether, manufacturing costs have been reduced by 20%, as certain assembly steps have become superfluous. As traditional means of assembly for the components and component groups are no longer required, support angles, holes or screws have also become obsolete. This results in yet more savings. In addition, the number of parts has been reduced by 70%, thus saving expenditures in logistics and procurement (Table 10.1).

Table 10.1. HP-Workstation: savings through EPAC as compared to a conventional product. Savings per application.

Part of the casing mechanism	70 %
Screw connections	95 %
Assembly time	50 %
Dismantling time	90 %
Transport packaging	30 %
Expenditure for the development of casing mechanism	50 %

10.4.4 Outlook

The EPAC is a development that points forward in ecoefficient product-design. In principle, the concept can be transferred to other products. Possible areas for application today range from information and communication technology equipment and white and brown goods to use in transport methods. Initial steps have already been taken in the manufacture of telephones. Here, placing the individual components in defined parts and holding them with place in the casing has also contributed to a reduction in assembly expenditure, while considerably increasing the recycling potential.

10.5 The Foron Refrigerator

Fig. 10.5. The Foron refrigerator. (Foron Haus- und Küchentechnik GmbH)

10.5.1 Introduction

Problems: CFCs and FCs

In 1994 the Foron Hausgeräte GmbH in Germany turned a pilot project into a fully developed, marketable product when it launched the first refrigerator without chlorofluorocarbon (CFC) and fluorocarbon (FC). The company has been putting more and more emphasis on the environmental qualities of its products since then. Its exemplary environmental commitment was rewarded with the first German Environmental Award, which it received in 1993, and the Innovation Award of the State of Saxony.

Based on the theory that CFCs and FCs present a considerable danger potential from an environmental point of view, the company was the first to use a liquid-gas mixture, consisting of propane and isobutane as a cooling agent. CFCs, which are still found in many household appliances, accelerate the destruction of stratospheric ozone. Especially chlorine-based trace gases are activated when reacting with ice and ice / nitric acid to such an extent that they cause ozone depletion. The ozone layer, which normally provides protection to all forms of life on this planet, absorbs the UV-B rays, which may encourage the development of skin cancer. CFCs

are also capable of storing heat and thus make a considerable contribution to global warming (greenhouse effect). This will have a major impact on ecosystems by increasing global temperatures, which among other things could lead to a shift in climatic zones and, ultimately, to starvation and environmental refugees.

On the basis of these facts it was decided at the Vienna Convention, in the Montreal Protocol and in its stricter revised version to completely eliminate CFCs from procurement and production. The Inquiry Commission on Preventive Measures to Protect the Earth's Atmosphere of the German government recommended, at the international level, the adoption and implementation of the global measures specified below as part of an overall strategy to contain the man-made greenhouse effect and to protect the earth's atmosphere.

At present, the objective is to manufacture the refrigerator from materials that are free from harmful substances such as CFCs. The use of CFCs in household appliances and refrigerators has been outlawed in Germany since January 1, 1995. However, producers of refrigerators are expected to go beyond this and take measures to ensure energy efficiency and the environmentally sound disposal of refrigerators.

10.5.2 Essential Product Innovation

The Foron refrigerator consists of several components (Fig.10.5) :

- The outer shell containing the insulating materials, which plays a decisive role in determining the energy consumption of the refrigerator.
- A refrigeration cycle, a hermetically closed system in which refrigerants with good thermodynamic qualities are used.
- The compressor, the core of the refrigerator. Its functioning depends on its design, the refrigerant and its adaptation to the aggregate.

The main aim of the company was to develop a refrigerator without CFCs and FCs. To achieve this, the following steps were taken:

Innovation: mixture of propane/isobutane

- The CFCs and FCs were successfully replaced by a mixture of propane and isobutane.
- For insulation purposes foamed polystyrene was used. This is a thermoplast which first undergoes a frothing process in which pentane is used and is then foamed with water vapour to fill certain defined hollow spaces.

10.5.3 Advantages of the New Concept

The mixture of hydrocarbons used in the refrigeration cycle can be handled safely and without causing any danger. It is a much more environmentally friendly refrigeration alternative. This mixture of refrigerants has several advantages. It

- does not have an ozone depleting potential;
- does not have a greenhouse potential; and
- remains in the atmosphere for only two or three days.

The thermoplastic polystyrene is no longer foamed with the help of the 'ozone killer' CFC. It can already be foreseen that this kind of environmentally sound foaming technology will eventually prevail on the global market.

By means of this pioneer work in the field of refrigerants and insulation, CFCs and FCs have been completely eliminated from the refrigerator and the company has put itself at the forefront of the development which very quickly has become the standard method used in the refrigeration industry.

Other environmentally relevant particularities of the Foron refrigerator: Apart from the development of a refrigerator without CFC and FC environmental thinking is implemented in the Foron refrigerators in other ways as well. The company puts its main emphasis on the following points:

- saving resources and continuously reducing pollutants by employing innovative production processes
- using recyclable materials and marking all materials in order to ensure environmentally sound disposal of the refrigerator after use.

In designing the refrigerator the company is putting more and more emphasis on environmentally sound technologies. Therefore, Foron has developed a refrigerator which sets a new technological standard in terms of energy consumption. According to an analysis conducted by the 'Technischer Überwachungsverein Bayern' in Saxony, Germany, the energy consumption of the refrigerator amounts to 0.5 kWh in 24 h based on a volume of 100 l. Since then, Foron has developed and launched energy-saver refrigerators, which consume only 0.35 kWh*100 l^{-1}*24 h^{-1}. By the year 2000 Foron aims to outperform its competitors by reducing energy even further. This will be done by designing a cylindrical refrigerator.

The resource consumption of the company was ascertained by establishing an environmental inventory (input-output analysis). For example, the volume of waste generated was considerably reduced by introducing

injection moulding and by cutting and recycling plastic waste in order to subsequently reintroduce it into the production process.

In order to continuously reduce the pollutants that are released during the production of the Foron refrigerator, new methods were introduced, for example in surface treatment. It is necessary to degrease sheet metals before they are coated. To do so, the company has been using de-emulsifying degreasers since 1993. In contrast to alkaline detergents with emulsifying properties this method allows separate degreasing and considerably improves wastewater treatment.

Conventional electrophoresis coating was eliminated completely and replaced by powder coating, which is substantially less harmful to the environment and also improved the quality of the coating. With this method solvents are no longer needed. This prevents environmentally harmful solvent emissions and reduces waste, which before the introduction of the process had to be classified as hazardous waste, by an amount of 10 t per year.

Small-parts surfaces and other materials are no longer treated by the company itself, but rather galvanized ones are purchased. This has caused a significant reduction in the heavy metals and amine loads in wastewater. However, the company should check whether subcontractors operate in an environmentally optimal way.

Environmentally sound disposal after the use of the refrigerator: The refrigerator was designed in such a way as to allow recycling of the materials it contains. The company was aware of its responsibility right from the beginning. Therefore it opted for recyclable materials and design that allow easy recycling. The individual components of the refrigerator were designed in such a way that reinstallation is possible without the use of specific tools. No composite materials were used that are difficult to separate or cannot be separated at all.

Since 1994 all materials used in Foron appliances have been labelled and the number of plastics used has been reduced significantly. Now up to 95% polystyrene is used in the production of the refrigerator and polyvinyl chloride has been completely eliminated. The design of the refrigerator meets both ergonomic and aesthetic requirements.

10.5.4 Outlook

It can be expected that the construction of the cylindrical refrigerator will give ecodesign another boost within the company. At the moment the refrigerator is sold only through special retailers and wholesalers in Germany and Israel.

10.6 The Wiesner-Hager Thesis Swivel Chair

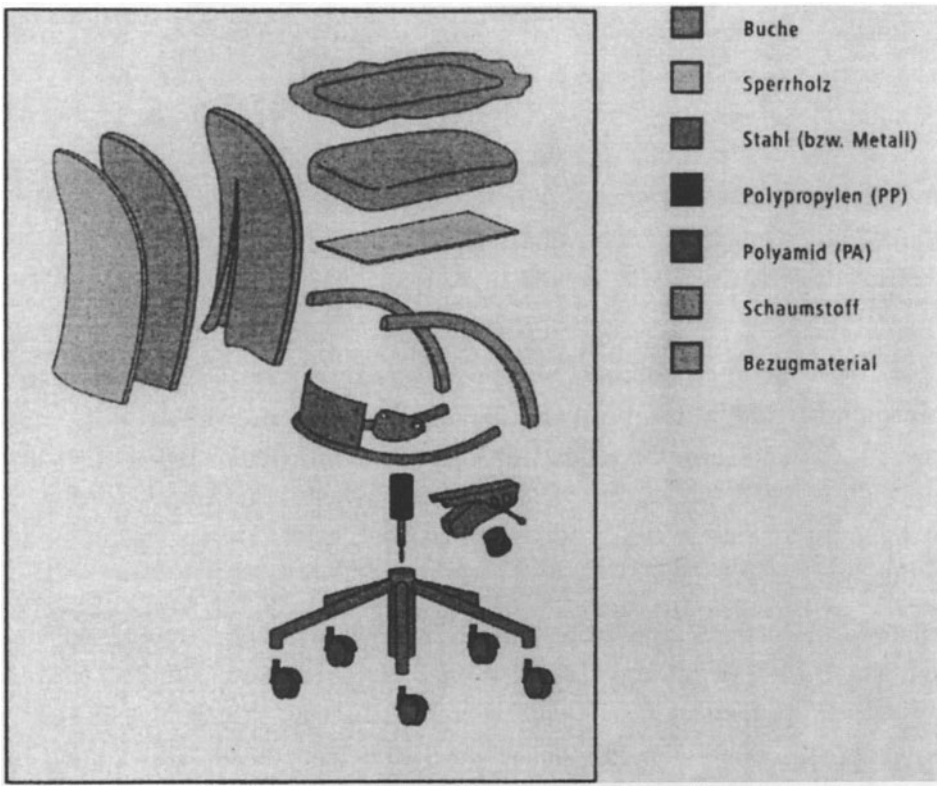


Fig. 10.6. The Wiesner-Hager office chair. (Wiesner-Hager)

10.6.1 Introduction

In designing this model special emphasis was given to the following objectives:

- Reduction of the technical functions to the necessary minimum.
- No sophisticated mechanical system (as the fulcrum points of both the seat and the backrest have been brought together on the same axle there is no need to cover the mechanical system).
- Only two elements to be handled by the user (regulation of spring strength by fixing in front position and variation of the seat height by rotating the upper part).

The ecodesign approaches include the avoidance of composite materials, cast metal and injection-moulded plastic parts. All components can easily be disjointed and disassembled, which allows for easy repair and maintenance as well as further use and recycling.

Avoidance of critical materials was yet another objective. This led to the complete rejection of the use of glues within the upholstery and the cloth. The covers are made of cotton denim and can easily be taken off and

washed. The spindles used to regulate the height of the seat and metallic powder coating are made of processed metal.

10.6.2 Essential Product Innovation

The main components of the product are made of wood and metal. All joints can be easily separated and all components can be detached from one another. Instead of the usual pneumatic spring, a spindle has been used to vary the height of the chair. Chromeplating has been completely eliminated. The packaging used for the product (PE bag and cardboard box) is taken back immediately after delivery of the chair and reused several times. The basic principles of ecodesign are the following:

Basic principles of ecodesign

- Ease of repair.
- Ease of disassembly.
- Recyclability.
- Ease of disposal.
- Durability.
- Well-matched functional lives of all components.
- Selection of materials, e.g. the use of regenerative materials, selection of materials for optimal functioning, avoidance of composite materials, marking and recycling of materials.
- Minimal costs of disassembly and disposal.

The next table illustrates the materials used in one chair. It also indicates the reclamation of materials after the life cycle of the product.

Table 10.2. Material components of the thesis swivel chair by Wiesner and Hager.

Materials	%	Reclamation
Steel	50.0	Scrapped for external materials recycling
Aluminium	9.0	Scrapped for external materials recycling
Wood	5.5	Incinerated for internal energy generation
Wood materials	24.0	Taken back by the supplier for recycling as regenerate material
PU foam	7.0	Depends on the type of cloth (materials recycling possible)
Cloth	2.5	Taken back by the supplier for recycling as regenerate material
Thermo-plastics	1.5	Taken back by the supplier for recycling as regenerate material
Elastomers	0.5	Taken back by the supplier for recycling as regenerate material

10.6.3 Advantages of the New Concept

Serious consideration and implementation of environmental requirements:

- Avoidance of plastics and moulded parts: the main components are wood and metal tubes and are easy to disassemble (all parts can be disjointed; cloth and upholstery are not glued together).
- Ease of repair
- No composite materials.
- Mechanical regulation of the spindle instead of pneumatic springs, as it is difficult to dispose of metallic powder coating instead of chrome plating (an odourless, low-emission and circulatory process).
- Durable and robust construction.
- Industrial metal wheels instead of plastic ones.
- Robust construction of welded steel tubes.
- Materials which aquire a patina (nubuk leather, denim, wood in natural colours).
- No sensitive snaps or catches.
- Timeless design.
- Unobtrusive, classic form.
- No unnecessary frills.
- Home appearance through emphasis on cloth and wood as basic materials.
- A good material and colour mix (cloth for the seat, leather for the backrest), may be used for special interior design effects.
- No 'sitting machine'.
- Easy to handle.
- Comfortable synchronous-effect mechanism.
- Ergonomically formed plywood parts for seat and backrest.
- Economical sizes and shapes allowing easy integration.

10.7 Launderettes with Long-Life Electrolux Washing Machines

Fig. 10.7. The self-service launderette. (Elektrolux-Wascator GmbH)

10.7.1 Introduction

Combining products with service

That it is possible to manufacture high quality appliances with a long life span and to earn money with them is demonstrated by the Swedish household appliance manufacturers Electrolux, who also make washing machines for launderettes. They succeeded in combining ecodesigned products with a service concept. Their semicommercial washing machines have an extremely long life span compared to normal household machines and fulfil several criteria with regard to ecodesign (cf. Chap. 6). These include:

Criteria fulfilled

- Function-oriented design.
- Increased life span.
- Saving resources.
- Minimizing the environmental impact of product usage.

10.7.2 Essential Product Innovation

Life span 30000 wash cycles

The machines are designed to reach a life span of up to 30000 wash cycles. In comparison to normal household washing machines this constitutes an increase by a factor of 8. Furthermore, the machines' water and energy consumption during use has been reduced. The machines can

be linked to a tank thus allowing water from the rinsing to be used again for the prewash in a new washcycle. This way, the water consumption can be reduced even further. Moreover, the machines are equipped with an automatic washing powder dispenser, which ensures that the optimal amount of washing powder required for the respective washing programme is dispensed. In addition, the controls can be updated. Compared to a household washing machine, the resource requirements for such a machine is lowered by a factor of 40 (Stahel 1991, p. 149).

The price of approximately DM 5900 per washing machine is considerably higher than for a normal household machine. However, taking into account the long life span, this still compares very favourably. In combination with a concept for communal use can pay off for both the manufacturer and the user.

10.7.3 Advantages of the New Concept

This product was developed within a marketing strategy focusing on the service rather than the sale of the product. In the tradition of communal laundryrooms in blocks of rented flats, this idea was adapted by opening self-service launderettes, which can be established as jointly owned enterprises. A professional operator buys the machines from the manufacturer, operates and maintains them and takes care of the marketing of the services. Several of these centres have already been successfully realized in Germany. In the Scandinavian countries, as well as in Switzerland, they have been in existence for quite some time. The users of such laundry centres acquire a magnetic card allowing them access to the laundry rooms and the use of the machines. Apart from the communication aspects of communal washing, the advantages to the users are that they do not have to invest in an expensive machine that is not used very often nor do they have to provide space for it in their living quarters. Furthermore, there is no risk involved with regard to water damage.

10.7.4 Outlook

The example shows that it can pay for the manufacturer to design products with a long life span and less negative environmental influence. It is attractive to market them as part of a service concept. This is one step for manufacturers in changing from suppliers of products to service enterprises which sell the use of their products rather than the products themselves.

11 The Future

In the future, more information will become available both on environmental problems and on environmental solutions. Several trends, in which SMEs will play an important role, will probably become more manifest. Some of them are dealt with below.

11.1 Resources

Environmental information

More environmental information will become available and will be transferred. This will lead to the re-evaluation of existing and the discovery of new environmental problems. Consequently materials, substances and products will be discussed and criticized. Changes will be required and new products will have to be developed. At the same time it will become increasingly clear that the current levels of production and consumption are not sustainable and cannot be prolonged far into the future. The population explosion that is predicted will mean that many new consumers, mainly in developing countries, will demand new types of products and services which meet their elementary needs and which cause less harm to the environment. This requires choices, i.e. new developments based on concepts such as lowering the level of material throughput in the developed world, making more use of the sun and of renewable resources, and various forms of sharing resources between people of the same generation as well as between generations (van Weenen 1996a).

As a consequence, many of the traditional nonrenewable material resources (including water) and nonrenewable energy resources will become more expensive. A shift in emphasis is likely to take place from materials and energy intensity towards service intensity. This will be stimulated not only because of the waste and pollution problems that we face, but also in order to cope with the increasing problem of unemployment. Gradually, more attention will be devoted to the immaterial factors which to a large extent determine well being. Political attention will also become focused on how to meet elementary needs at a level of high and sustainable quality.

SMEs can anticipate these changes and respond in a proactive way by looking for good examples in their own area, industry or country, but also by making contacts with SMEs and SME organizations abroad for exchange and cooperation. It is likely, however, that at the same time

interest in local conditions, in locally available materials and energy resources and knowledge will increase.

11.2 Product Development

Sustainable development

Societies will discover the importance of using sustainable development principles as starting points for the design and redesign of their production and consumption structures. Examples of this are the use of more solar energy and other renewable resources, and the use of less polluting resources and fossil fuel. Drastic reductions, by a factor of 10 - 20, in the use of materials and energy are being discussed. But this quantitative approach is likely to be replaced by a qualitative one. It will not be adequate only to reduce material and energy intensity considerably. It will be equally important to be more selective, to think of resource and energy properties and the way resources, energy and nature are connected, and to consider how the interconnectedness of nature may inspire us in our attempt to realize sustainable development. This is the approach which is required. It will not be enough or even appropriate to just move from a high to a low volume; it is rather the composition of the music which really counts.

Much more attention will be devoted to the required product functions and to alternatives. By reformulating consumer needs and reassessing ways in which these can be met - that is if absolutely necessary - new products, services or systems may be developed which offer better performance both for the consumer and for the environment.

Return policy

The political development concerning the return of several types of consumer products to their producers will hopefully lead to a debate on the product life itself, the inherent quality of the product and the ways in which the product can be improved or replaced. At the same time the 'take-back' approach might lead to new process-product systems and concepts in which responsibility and ownership remain to a large extent with the producer or manufacturer. Thus new process-product-service combinations may emerge. New product distribution and redistribution systems may lead to new markets and innovations beneficial both from an economic and ecological point of view.

11.3 Society

New environmental demands

In the future more contacts will be made between stakeholders in the product life cycle such as suppliers and consumers. They will formulate new environmental demands and wishes. It is important for SMEs to be one step ahead of these newly emerging requirements. This can be realized by bringing in the best possible knowledge and ideas from workers, consumers and environmentalists. In view of the growing international competition, environmental aspects will play an important role. Through international cooperation and exchange many improvements can be realized and new ideas and concepts can be developed jointly. Thus, new markets may emerge and innovation capacity will be stimulated. This effect can be multiplied by a changing role of government, which - if SMEs give them reason to do so - could become more stimulating than restrictive. Because they operate locally, with potentially good means of communication, and have human imagination as their main resource SMEs can provide the basis for a new economically secure and sustainable future (van Weenen 1996b).

12 Appendix

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A.2 Institutes

IZT Institute for Futures Studies and Technology Assessment, Berlin, Germany

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The Institute for Futures Studies and Technology Assessment was founded in 1981. The emphasis lies on future studies and the analysis of the development and introduction of new technologies as well as the assessment and evaluation of the economic, political, ecologic and social consequences of such technologies.

Furthermore, the IZT develops strategies and tools with regard to technical design and ecologic and social structural changes in society and the economy.

The topics the institute is dealing with include in particular sustainable development, material-flow management (within an enterprise and between enterprises), closed substance cycles economy, ecobalancing, integrated chain management, environmental product-design and product evaluation as well as ecologistics.

An example of the varied projects with enterprises is the cooperation of the IZT with Loewe Opta GmbH. With the support of the BMBF (Federal Ministry of Education, Science, Research and Technology), an innovative concept for a disposal-friendly television ('green television') was developed between 1992-1994. The IZT and Loewe Opta GmbH together received the 'Environmental Steel Innovation Price 1994' for this development.

IVAM IVAM Environmental Research, Amsterdam, The Netherlands

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IVAM Environmental Research is the environmental research institute of the University of Amsterdam, specializing in interdisciplinary research as well as in practical advice for industry and government. The institute is involved in international research in the field of sustainable use of materials and energy. Key concepts are life cycle design, cleaner production, life cycle assessment and integral chain management. Development of innovative analysis and improvement tools for life cycle design in industry is an important activity.

IVAM Environmental Research have assisted several companies in projects aimed at the environmental sound design of products, such as hot-drink machines, personal computers, drying machines, building components, cables and packaging. The institute has an extensive product study data base and has conducted several full-scale life cycle assessments. In order to guarantee the quality of the work, the institute is involved in the international development of assessment methods, within the framework of the Society of Environmental Toxicology and Chemistry (SETAC).

The United Nations Environmental Programme Working Group on Sustainable Product Development (UNEP WG-SPD) was established at the beginning of 1994 at the University of Amsterdam. It is a development of the UNEP-Industry and Environment Office - Programme Activity Centre's (UNEP/IEO-PAC) Cleaner Production Programme. The group was formed as a response to 'Agenda 21' of the UNCED Rio de Janeiro Conference (1992) which called for changes in production and consumption patterns towards a sustainable future.

The main activities of the UNEP WG-SPD involve the 'research programme', and the 'network programme', which have developed an international network of SPD experts in over 600 organizations worldwide. The number changes as the network matures. The Centre advises governments, industries, universities and NGOs and it conducts research on the concept of SPD. The emphasis is on new design approaches and on the properties and

the availability of resources in relation to elementary needs. In particular, the work is concentrated on the needs of future generations in developing countries.

INETI Instituto Nacional de Engenharia e Tecnologia Industrial, Lisboa, Portugal

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The INETI (National Institute of Engineering and Industrial Technology) is an agency for research, development and demonstration within the Portuguese Ministry of Economy, with the main responsibility of contributing to the modernization of industrial companies and the technological system that support them.

One of INETI's scientific and technological priorities is Environmental Technologies which it converts into integrated and coherent programmes and projects within the Institute of Environmental Technologies - ITA.

The ITA is a public institution devoted to Research, development and demonstration and technical, technological and laboratory assistance, that covers the following main areas: cleaner production, environmental management systems, environmental audits, life cycle assessment, ecodesign, and environmental impact and monitoring studies.

In all these areas ITA carries out research and development. It provides consultations and training in order to give effective support for solving environmental problems in the industrial sector.

IÖW Institute for Ecological Research in Economics, Vienna, Austria

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Tel: ++43-1-587 21 89
Fax: ++43-1-587 09 71
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The „Institut für Ökologische Wirtschaftsforschung IÖW" (Vienna Institute for Ecological Research in Economics) was founded in 1990 as a nonprofit organization. The IÖW is engaged in research projects in the field of ecobalances, life cycle assessment, environmental information systems, environmental management systems, pollution prevention and ecoaudits.

In the last five years the institute has been involved in about 25 company projects and has performed several research activities for public organizations. The main clients of the institute are the Austrian Ministry of Science and the Ministry of Environmental Affairs.

The IÖW managed the Austrian EUREKA Project 'PREPARE', where pollution prevention projects were performed in 12 companies as well as corresponding research activities together with the Institute for Process Engineering at the Technical University in Graz. The outcome of this project was an Austrian version of the USA EPA Pollution Prevention Manual with an improved methodology integrating the EMAS-Regulation and ISO 14001.

The founder of the IÖW, Christine Jasch, is also an accredited environmental verifier under the EMAS Regulation.

The IÖW actively participates in ISO TC207 Standardization of Environmental Management.

A.3 LCA Software Tools

Several computer programmes have been developed to support LCAs. Due to the wide range of applications it is not possible to indicate the best one because such a thing does not exist. The important thing to keep in mind is that software tools will not perform LCA for you, but they can help you in your work: the best choice depends on your own goals. However, you do not need software tools at all to perform a good LCA study. They will only be useful, like any other kind of software, if you understand them very clearly. Some rules of thumb:

1) Trust your own knowledge.
2) Have your own goals in mind.
3) Always ask for a demo diskette first.

Some existing programmes are introduced in alphabetical order:

- *Boustead Model*

  English, MS-DOS, Open University, United Kingdom

  Contains data on energy and processes.

- *EkoTool*

  English, MS-DOS, Soil and Water, Finland

  For optimizing linear models. Treats environmental questions as costs.

- *EPS 2.0*

  English, Windows Excel, Swedish Environmental Research Institute, Sweden

  Experimental programme working with Excel 4.0, intended to assemble data according to the rather complex EPS system. The system works out the social costs of pollution. The programme can calculate uncertainties and make a sensitive analysis.

- *Gabi-Basis*

  German and English, Windows, IKP University of Stuttgart, Germany

  For inventory analysis. Data on energy, transport, emissions and waste management. Will include evaluation.

- *IDEA*

  English, dBase IV, IIASA-Austria and VTT-Finland

  For inventory analysis. Extensive data base on basic materials, energy, production and transport.

- *KCL-ECO*

  English, Macintosh, The Finnish Pulp and Paper Research Institute, Finland

  For inventory analysis. Flexible use and graphical interface. Data focusing on chemical forest industry.

- *LCA Inventory Tool*

  English, Windows, Chalmers Industriteknik, Sweden

  For inventory analysis. The user can draw the process chart on the screen and fill in all the data for each process. The programme then calculates the interferences table. It cannot carry out any assemblage steps and it cannot compare products.

- *Öko-Base 2*

  German, MS-DOS, Migros,Switzerland

  Data base for analyzing and selecting packaging and products. The programme only gives results in Ecopoints. The data base is closed and the data cannot be changed. Based on the BUWAL method and data.

- *Öko-Pack*

  German, MS-DOS, LSS Lahyani Software Solutions, Switzerland

  For inventory of packaging. Based on the BUWAL method and data.

- *PEMS*

  English, Windows Excel, PIRA, United Kingdom

  For inventory analysis. Contains industrial data base, which is regularly updated. Will contain evaluation elements.

- *PIA*

  Dutch and English, MS-DOS, TME, The Netherlands

  For inventory analysis. Assembling and comparing data is not possible. It has a relatively large data base related to Dutch industry, on energy production, transportation and waste treatment.

- *Procter & Gamble*

  English, Windows, Procter & Gamble's Technical Centre, Belgium

  For inventory of packaging. Based on the BUWAL method and data. Distributed freely.

- *Simapro 3*

  English, MS-DOS, PRé, The Netherlands

this is a DOS programme but works with a mouse and a Windows-like user interface. It is suitable for the inventory phase as well as the evaluation phase. Extensive life cycle analyzes can be worked out, but it is also suitable for designers. Several evaluation methods are possible. A large data base is included. There are two versions: an analyst and a designer version. The latter version is a bit simpler.

- *TEMIS/GEMIS*

  English and German, MS-DOS, Öko-Institut, Germany

  For analyzing different energy systems, transportation systems and material process chains.

- *TEA*

  English and French, Windows, Ecobilan, France

  For inventory of complex products. Data base on the main materials used in industry. Includes costs module.

- *Umberto 1.5*

  German, Windows, ifu, Institut für Umweltinformatik, Germany

  For inventory of materials and complex products. A data base of main materials used in industry.

For more information see:

- Atlantic Consulting: LCA-software buyers guide, London, 1994
- Society for the Promotion of LCA Development: LCA source book, a European business guide to life cycle assessment, Brussels, 1993
- Weidema, B.P.: Environmental assessment of products, 2nd edition, UETP-EEE, Helsinki, 1993
- Schweizerische Gesellschaft für ökologisch bewußte Unternehmensführung (ÖBU*):* Marktübersicht Ökobilanz Software 1995, St.Gallen, 1995

A.4 Life Cycle Assessment on the Web

(Source: LCA news a SETAC-Europe publication, March 1996, Volume 6, issue 2):

http://www.cfd.emit.edu.au/Research/LCA.html

Life cycle assessment

http://www.doe.ca./ecocycle/

Ecocycle newsletter on life cycle tools, management and product policy

http://www.ivambw.uva.nl/ivam/product/lcadata.html

IVAM LCA data base

http://www.iso14000.com/scs/ISO14000i

ISO 14000 standards

http://ie.uwindsor.ca/choil/

M.A. Sc. thesis by Athelstann Choi

http://ie.uwindsor.ca./ecdm/courses

Courses presented by the ECDM lab

http://ie.uwindsor.ca/ecdm/lab.html

Website, references to other related internet resources and lots of other information

http://ie.uwindsor.ca/ecdm/projects/sandlca.html

Sand LCA

http://ie.uwindspr.ca./paper_02.html

Environmental conscious manufacturing

http://ie.uwindspr.ca./spicer/copie1.html

17th Computers and industrial engineering

http://duto02.tudelft.nl/EnvEnrg/19970331.mfl

Researching LCA accuracy

http://unixg.ubc.ca:880/ecolabel/cel.html

Centre for Environmental Labelling

http://www.io.org/-lca

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LCA software tools and general information

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